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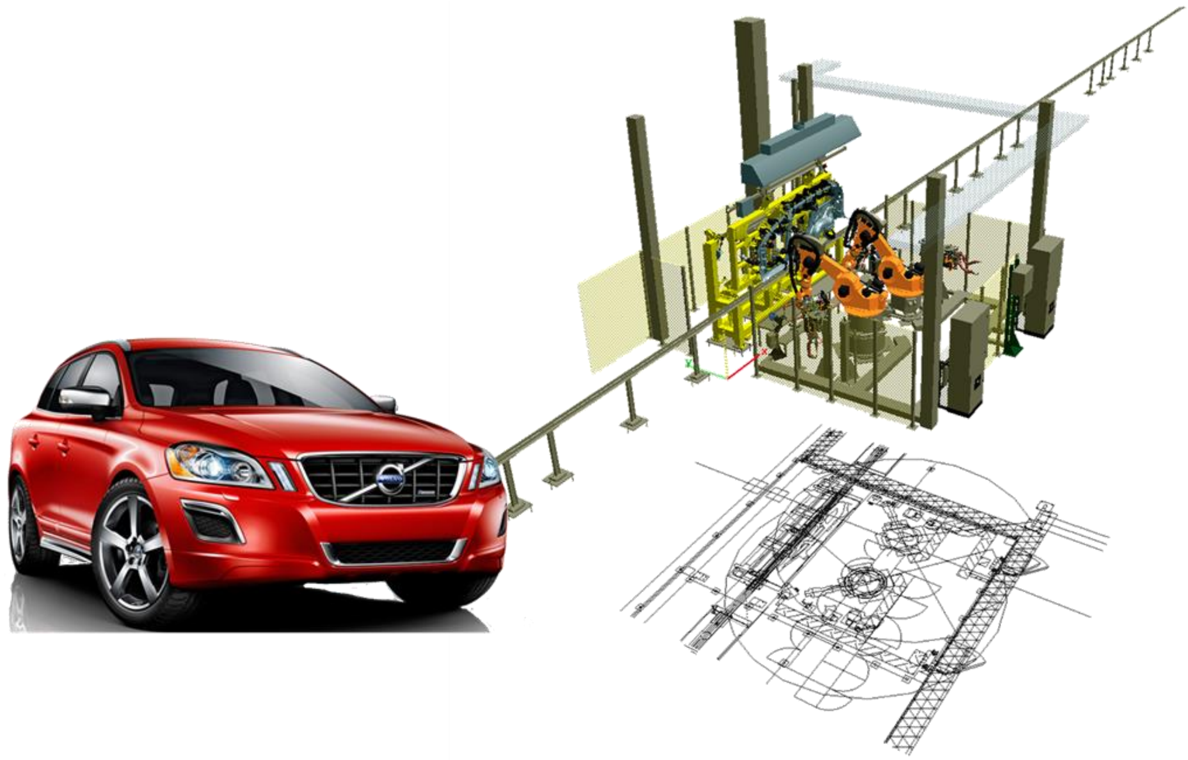

Data Acquisition Methods for Discrete Event Simulation

A Case Study at Volvo Cars Torslanda

Master's thesis in Production Engineering

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Department of Product and Production Development
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Cover:
The cover picture is a representation of the StreaMod project.

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Abstract

The following thesis work compiles a comprehensive theoretical review of Discrete Event Simulation Project methodology, with focus mainly on the Input Data Management process and the requirements of a study case within the automotive industry. A thorough gap analysis between the simulation input requirements versus the existing information in the organization was made to illustrate the shortcomings in information availability and quality. The method to collect input information for the simulation model has been broken down into: data collection, data processing, and interfacing. Results are based and discussed upon a case study of a real body shop production scenario at Volvo Cars, in order to illustrate what information sources were explored, used, and furthermore what kind and form of data could be extracted from them. Specific solutions to compile the input data for the simulation study are presented and discussed. Integration potentials with other existent systems in the company were explored and possibilities on further research are appointed. Finally, several suggestions towards data collection in the current organization and modeling automation for the specific production case are discussed. The importance of sufficient quality of data is pointed out in the conclusion, as the following areas were found lacking in the VCT case: steering logic documentation, disturbance logging, processing time and transportation between lines.

Keywords: Input Data Management, Discrete Event Simulation, DES requirements, information sources in automotive industry.

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Definition of terms

A-factory	– Car bodies factory at VCT
AutoCAD™™	– CAD layout program
BIW	– Body in white, car body before painting.
BOM	– Bill of Material
BOP	– Bill of Processes
BSI	– Body Side Inner
BSO	– Body Side Outer
CBS	– Corporate Business System
Chalmers	– Chalmers University of Technology
CTView	– VCT Webpage application to explore historical information on station times
DES	– Discrete Event Simulation
DOE	– Design of Experiments
DSS	– Decision Support System
EBOM	– Engineering Bill of Material
eBOP	– electronic Bill of Processes
EOM	– Electric Overhead Monorail
eMS	–Brand of manufacturing planning database Tecnomatix™
ERP	– Enterprise Resource Planning
LH	– Left Hand side
Line-54	– The investigated production line at VCT, car body framing process
MBOM	– Manufacturing Bill of Material
MDT	– Mean Down Time
MES	– Manufacturing Execution System
MRP	– Manufacturing Resource Planning
MPS	– Material Planning System
MTTR	– Mean Time To Repair (or just TTR)
MTBF	– Mean Time Between Failure (or just TBF)
OEE	– Overall Equipment Effectiveness
OEE Portalen	– VCT log monitoring system for the Virtual Device at TA
PD	– Process Designer™
PDM	– Product Data Management system
PLC	– Programmable Logic Controller
PLM	– Product Lifecycle Management
RH	– Right Hand side
SCADA	– Supervisory control and data acquisition
StreaMod	– Research project: Streamlined Modeling and Decision Support for Fact-based Production Development
SPC	– Statistical Process Control
SUSA	– Disturbances log system at TA
TA	– Torslanda A-Factory
TAP	– Torslanda A-fabrik Produktionstyrning
TATS	– TA Terminal Services, monitoring system website for TA
TATS Script	– A web script that queries a station at TA for historical logged data in the VD

The thesis	– The current investigation of this thesis
VBA	– Visual Basic Application
VCC	– Volvo Cars Corporation
VCT	– Volvo Cars Torslanda
VD	– Virtual Device, SCADA system at TA
Vinnova	– Swedish Governmental Agency for Innovation Systems

1 Introduction

"Discrete Event Simulation (DES) is one of the most powerful tools for planning, designing and improving material flows in production" (Skoogh et al., 2012). Productivity solutions, which used to be tested in a real production environment, can now be tested in the virtual world. From the authors' perspective resource savings and more accurate investments are two of the positive outcomes from production simulation modeling. However, the process of building the model can be anything but straightforward as there is often a lack of stored simulation input data in corporate business systems. This yields in increased time consumption as the data collection and quality verification often needs to be completed manually. The thesis investigates this potential improvement further to put light on essential parameters needed for an automatically created and updated discrete event simulation model.

1.1 Who is the customer

The thesis is made within the field of Production Engineering at Chalmers University of Technology, also referred to as "Chalmers", as part of the research project "StreaMod" in which several industrial and academic partners are involved. Specifically the thesis will benefit the Manufacturing Engineering department of Volvo Cars Corporation at their Torslanda production site in Gothenburg, Sweden, hereafter referred as "VCT".

1.2 Background

VCT currently produce six different car bodies in the same flexible production line. Increased complexity and reconstructions as well as new model introductions have affected the efficiency of the production line through the years and invalidated previous research studies. In order to stay competitive VCT, through the "StreaMod" project, aims to cut the lead time from program start to delivery of the first unit from 36 to 20 months and reaching an Overall Equipment Effectiveness of above 85% in their running production. These world-class levels require the use of Virtual Manufacturing tools to enable production development engineers to have a powerful and responsive decision support system.

In order to address this industrial need, VCT and Chalmers along with StreaMod partners, have been granted Vinnova (Swedish Governmental Agency for Innovation Systems) funds to research on the project StreaMod: "Streamlined Modeling and Decision Support for Fact-based Production Development", and the thesis work is considered as an initial step towards the general project goal.

One of the current main problems for StreaMod's industrial partners is the extensive time-consumption in simulation project, mainly due to inefficiencies in data management (>30% of project time) and experimentation. Production development engineers waste a significant amount of time collecting and processing data to validate simulation models, before they are able to prove concepts or generate value out of experimentations.

1.3 Problem definition

Data collection is a manual and time consuming task, necessary in the process of creating a Discrete Event Simulation (DES). A task which tend to add distraction in the work of a production simulation modeler, who end-up spending energy and time collecting input data instead of focusing efforts to generate and validate improvements aimed at the production line. Therefore, the thesis investigates two research questions that could provide a solution:

RQ1. What are the requirements for input data to generate a simulation model that addresses a common engineering question?

RQ2. How can a simulation model be integrated to the production data sources to automate the model creation and update of the required input information?

1.4 Purpose and goal

Previous studies have shown that it is possible to automate input data for simulation models but further research work should be done to investigate which and how specific data from the different sources at VCT can be used in a Decision Support System (DSS) through a DES study case scenario.

In the thesis, a gap analysis of a specific study case in the current production line at VCT is presented in order to help clarify availability and quality of the production data. Investigated data will be directly related to the input requirements for a more efficient future integration to an automatic simulation model creation and update. It has been decided to take a section of the A-factory as delimitation of the study case, further information on the line can be found in section 1.6. Exploration within the scope will be done to find which information sources that are reliable and of interest for the most frequently asked questions in production, learn how to manage them and how to integrate a suitable simulation model.

The goal is, through input data management, model generation and a gap analysis, to provide a foundation with sufficient quality for the future creation of an automatically generated and updated DES model that can function as pioneer towards the development of the Decision Support System for production and maintenance engineers within the time period of February to June 2014.

1.5 Thesis limitations

The thesis will not include any kind of application or script to extract process and input the data automatically from the several available databases into the simulation model. The intention of this project is rather to point out the existence, location and form of the data needed as input for the simulation case.

1.6 Study case: Body shop framing process simulation

As mentioned previously in section 1.4, the area of study is limited to a section of the body shop at VCT. The intention of building the simulation model is to realize what kind of information is needed in order to do a capacity study of the production line, and compare the results with reality. The main process of this selection is Line-54, or Framing Line, where under body, left and right sides, and roof beam lines converge. The first process station of the Framing Line, station 11-54-020, is considered to be the heart of the body shop factory due to its complexity and importance concerned the overall process of the body production. Station 11-54-020 is the actual assembly point for sides, roof, and under body and is thus considered critical to keep from starvation. For this reason the thesis will include the lines 51, 52, 56 and 57, producing the complete sides, which have been pointed out as possible causes to starvation issues. Therefore the simulation model will be limited according to *Table 1*.

Process name	Line	Description
Framing	11-54	Main process, 11-54-020 framing station
Body Side Outer (BSO) -RH	11-52	Process+ Assembly of BSI + Transport system
Body Side Inner (BSI) -RH	11-56	Process + Transport system
Body Side Outer (BSO) -LH	11-51	Process + Assembly of BSI + Transport system
Body Side Inner (BSI) -LH	11-57	Process + Transport system
Roof Beams	11-54	Simplified representation
Under Body	11-43	Simplified representation

Table 1 Line description over the study case at VCT

The production process is similar for the two side lines. The Body Side Inners (BSI) are assembled in lines 56 and 57 which have dedicated fixtures for each product type, therefore the transport system must be able to change the fixtures based on order. The BSIs are processed in several stations before being transferred in the last station from the fixture to a hanger transport system, which serves both as a buffer and a conveyor. The hanger system is a so-called electric overhead monorail (EOM) system in the roof. The hanger system moves the BSI to the assembly station (11-51-060 or 11-57-060) at the Body Side Outer (BSO) line where the BSI is assembled into the correspondent BSO.

At the BSO line the transport fixtures are also product type specific. When the first station starts the transport system must have the correct carrier type available before entering the actual line with several processing stations, including the previously mentioned BSI assembly. Finally the BSO is transported to the Framing Station.

The Roof Beams line is a short process with only a few assembly stations. The under-body line is complex and will have simplified representation in the thesis. Section 4 Simulation Model, contains further information about the production system. *Figure 1 Process flow of VCT Body Shop*, shows the scope of the simulation project within the enclosed area.

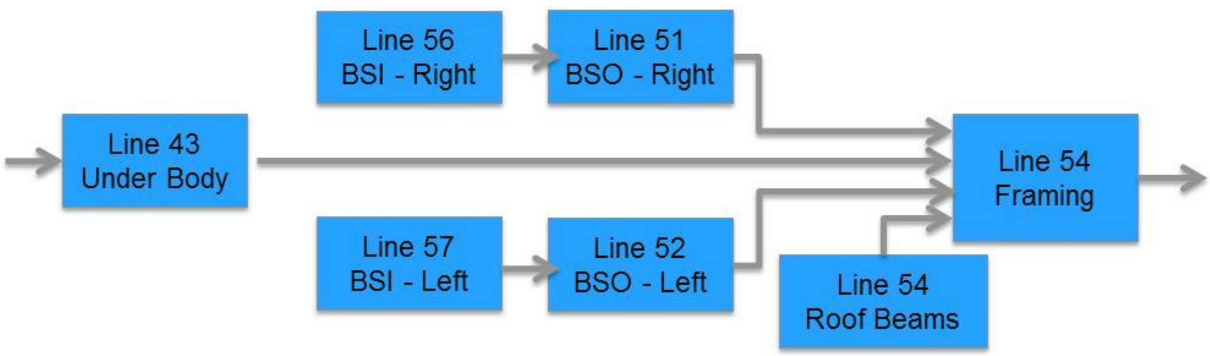


Figure 1 Process flow of VCT Body Shop

2 Theory

The thesis is supported by a literature review in the areas of DES-project methodology, input data management and quality of data through statistical analyses.

2.1 Simulation Project Methodology

A successful simulation project is run according to guidelines. This reduces the risk of failure within the project and enables a time plan to be kept. Musselman (1994) suggests one approach with eight guidelines: (1) Problem definition and clear result objectives, (2) Model conceptualization, (3) Data collection, (4) Build model, (5) Verification and Validation, (6) Analysis, (7) Documentation, and (8) Implementation, see *Figure 2*.

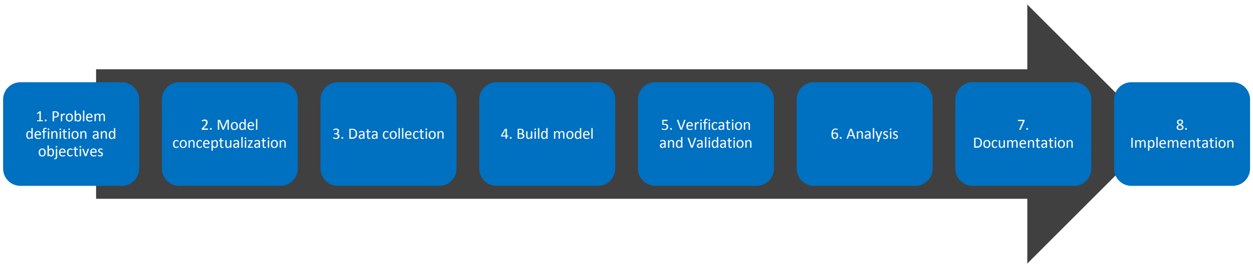


Figure 2 Simulation methodology described by Musselman (1994)

The approach is supported by Banks (1998) who divides the steps under twelve similar headlines, where the logic between the steps is added for a more comprehensive and detailed overview, see *Figure 3*. The methodology described by Musselman and Banks is verified to be valid still according to Williams and Ülgen (2012).

A simulation project should be started with (1) a well-defined *problem formulation* and (2) *setting clear objectives*. Solving objectives out of the project scope is time consuming and does not add value to the project, thus it is important to listen to the customer and have precise and clear objectives defined from the very start, Musselman (1994). Focus is kept throughout the project by communicating information in advance and using shorter and more frequent deliveries. It can also be advisable to create a reference point by asking the customer to predict the solution. The conclusions, drawn from the simulation project, can then be clearer to the customer in the end.

The next step of the project is (3) the *data collection* process. The sample size of collected data should be around 200-230, Banks (1998) Skoogh and Johansson (2008), Perrica et al. (2008). A smaller sample size reduces the quality of the input data and makes the analysis less reliable. A larger sample size has shown to not improve the quality noticeable, Banks (1998). The collected data should be questioned with source and content, together with stated collection methods. Consideration to these questions enables an estimation of the data-sensitivity thus increasing the model robustness with more accurate output. When absolute data cannot be found, educated assumptions can be made in order for the project to move on, Musselman (1993). A previous Master thesis in the area of simulation, by Andersson and Danielsson (2013), experienced this situation and the project could only move forward by making such an educated guess.

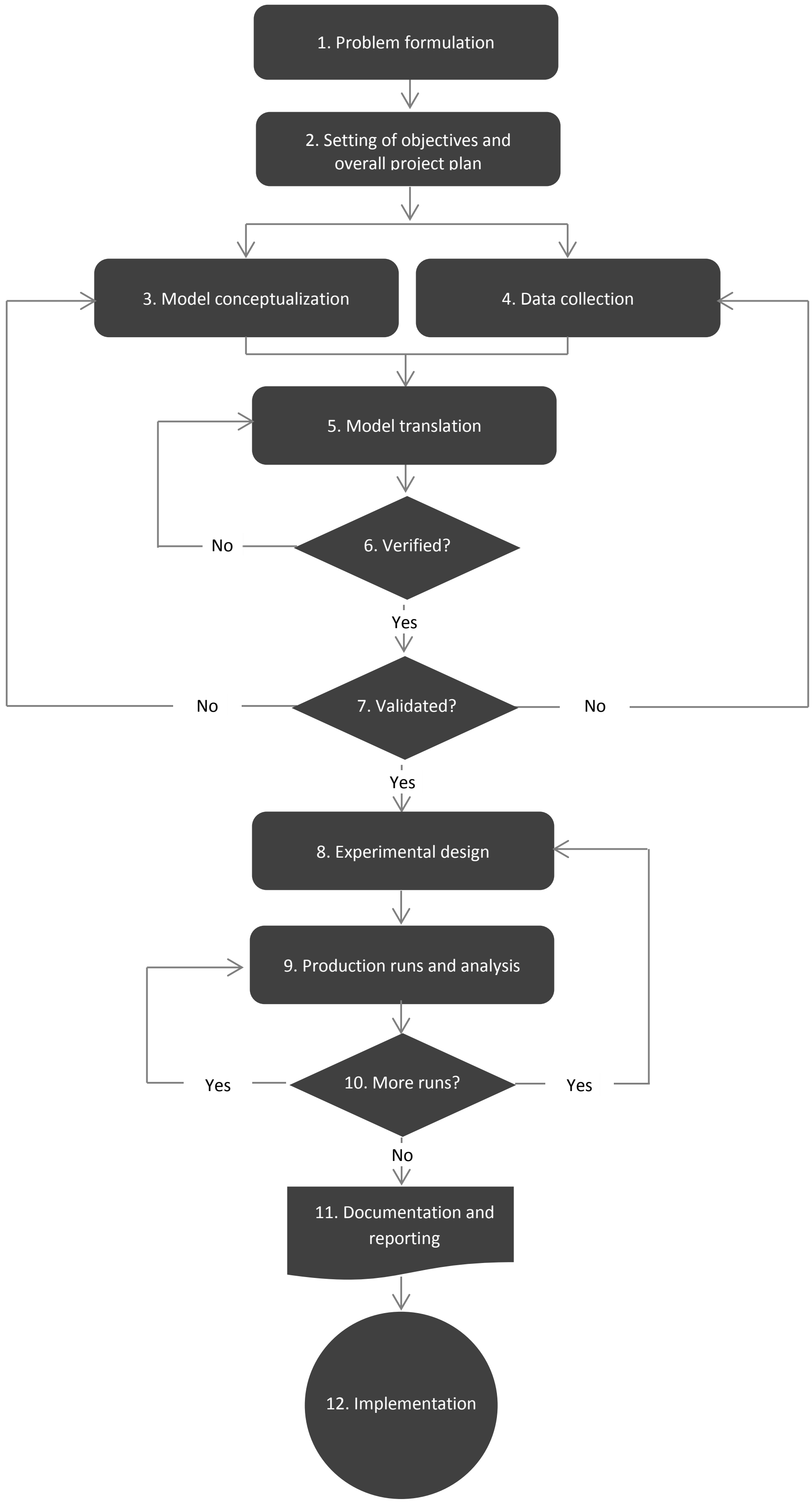


Figure 3 Simulation methodology by Banks (1998)

Banks (1998) suggests (4) a *model conceptualization* parallel to the data collection process. From these two steps the actual *model* (5) is built continuously. By starting simple and only model basic functions increases the modelers' ability to fully understand the system's structure and operating rules, Banks (1998). Increasing the complexity and adding on functions to a basic model makes it easier to understand produced outputs, Musselman (1994). The added detail should be based on stated objectives where components are only added when impacting decision making or confidence building, Banks (1998). The building of the model includes input procedures and interfaces, division of model into smaller logical elements, separation of physical and logical model-elements, clear documentation in the model, and leaving "hooks" to enable future extensions of the model, Banks (1998).

Throughout the building of the model the functionality should be assessed continuously by *verification* (6) and when acceptable the model should be (7) *validated* to be an accurate representation of the real system, Banks (1998). It is important to have an accurate representation to be able to produce useable experimentation results. Musselman (1994) emphasizes on the importance of involving customers in this phase as the customer often request changes along the way of a simulation project. Even a small change may cause great impact on the total system. Thus customers should take part of change request meetings in order to keep in line with the initial scope and objectives of the project, in order to keep changes at a minimum or when absolutely necessary.

The *experimental design* (8) is the preparation step of scenarios which are to be investigated. This step includes length of simulation run, number of runs, and initialization, Banks (1998). Step (9) *production runs and analysis* is connected with step (10) concerning the question if *more runs* are needed. First the simulation model is run according to the experimental design and secondly the results are analyzed to conclude the performance depending on experimental scenario. Questioning the system output and understanding the model's limits is typically a part of the analyze phase, Musselman (1994).

Finally step (11) *documentation and reporting* is done by the modeler, describing the model and its functionality. According to Banks (1998) this is an important step for future use of the model by analysts either for further analysis or creation of new scenarios which demands changes in the current simulation model. The end of the simulation model project is when sufficient information has been provided for the customer to make a decision on *implementation* (12).

2.2 Input data management

The collection of data input to simulation modeling projects is stated to be the most time consuming activity requiring more than 30 percent of total project time according to company studies, Skoogh and Johansson (2007), Perera and Liyanage (2000). It is also a crucial part to enable accurate outcome from the simulation model, Robertson and Perera (2002). Therefore it is essential in the thesis to provide a clear view of the data collection process. This section provides a description of data classification and different methodologies used today for data collection.

2.2.1 Data collection methodology for input data management

In general companies today do not utilize a standardized method for data collection. This was a discovery by Skoogh and Johansson (2009) based on industry case studies. From this discovery a method was developed, see *Figure **5***, from the definition of input data management as "*the entire* *process of preparing quality assured, and simulation adapted, representations of all relevant input data parameters for simulation models*".

Data acquisition is addressed in detail by Johansson and Skoogh (2008) by breaking down the data acquisition step of Banks methodology into a process of input data management. This process can be defined into three main parts: Data collection, data processing and interfacing.

2.2.2 Data collection

A simulation is built upon the information that is available about the process, the resources and the material flow. Qualitative and quantitative information can provide the simulation modeler with the understanding that is needed to correctly represent the system. Qualitative referring to the descriptions and qualities of the process, whereas quantitative refers to the numerical values that have been registered about the processes. Nevertheless, for the purpose of the thesis only quantitative data will be evaluated and further analyzed. It is out of the thesis scope to automate the creation and update of a model with qualitative data, as stated on RQ2 in section 1.3.

Some typical data sources used in input data management are:

- Corporate Business Systems (CBS)
    - ERP
    - PLM
- Project specific data
    - Layouts
    - Project Documentation
- Collected data
    - From SCADA
    - Time studies
- External reference systems
    - Suppliers
    - Industry databases

The CBS is the combined software systems which gather and manage data within an organization, Robertson and Perera (2002). Enterprise Resource Planning (ERP) is a typical example of a CBS.

Project specific data is data created within a project for the own purpose of the project. Layouts and general project documentation are good examples.

Collected data is available data which has been taken directly by measurements in the production, such as time studies, or from data collection systems within the organization.

External reference systems are information or data which is gathered from external sources. Examples of these are suppliers, knowledge from line builders in the automotive industry, and general industry databases for equipment.

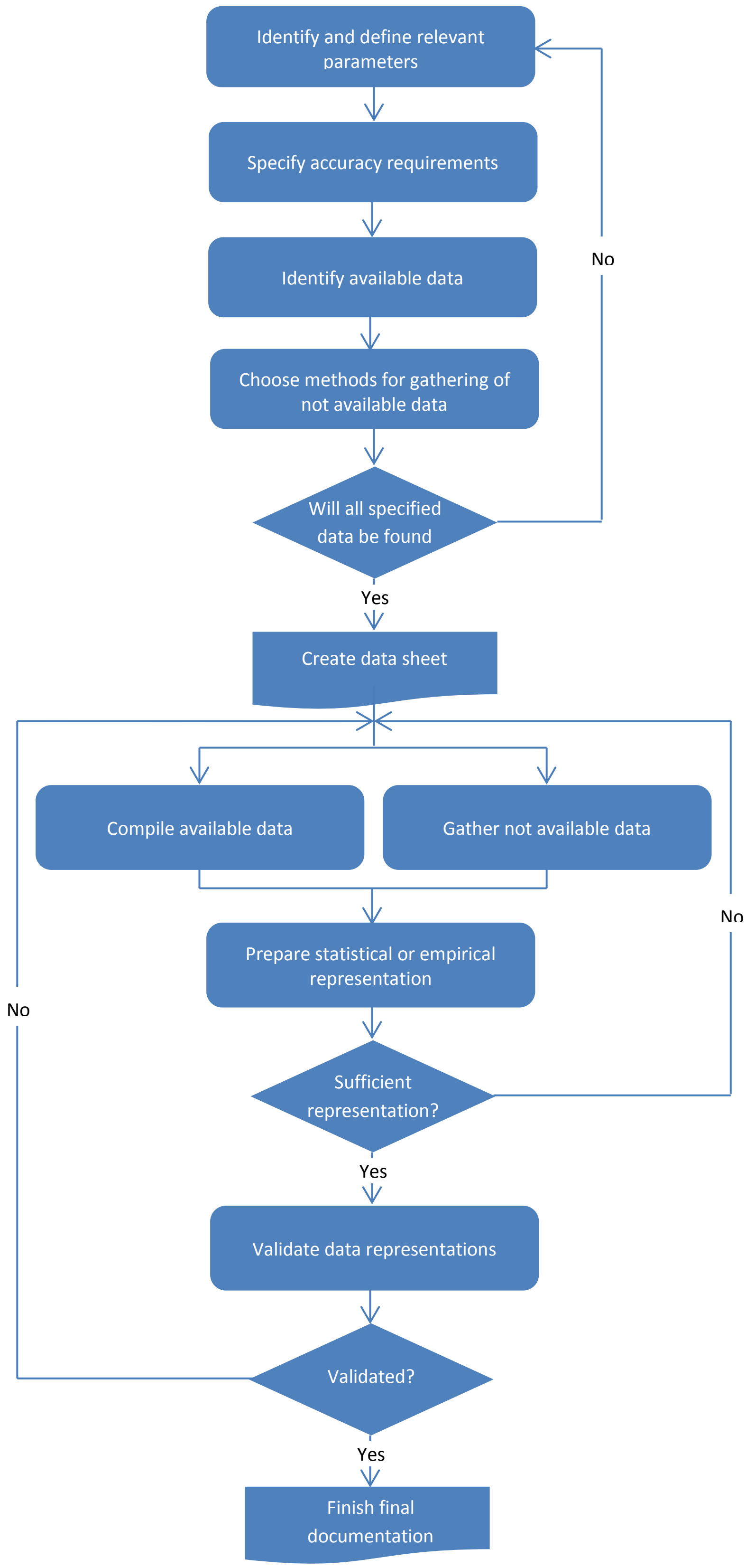


Figure 4 Input data management methodology by Skoogh and Johansson (2009)

The data sources get affected mainly by conditions like size of the organization and technology in the equipment. In industry it is very common to find the information sources to be spread across the enterprise (Robertson and Perera, 2002), which makes it difficult to concentrate all the information a broad simulation project would need. Additionally, the amount of historical information can vary significantly depending on the matureness of a manufacturing system, whereas it is a planning or current production stage, engineers might use different purpose applications and systems to extract information about the scenario to model.

Data classification

Data can be classified in three different groups according to *Table 2*, Robinson and Bhatia (1995).

Table 2 Data classification

Category	Data availability
Category A	Available
Category B	Not available but collectable
Category C	Not available and not collectable

As described in the previous section the first step is to start mapping the data according to simulation model objectives and organize it in the three groups. The process of arranging available data in category A is straightforward. Category B data is more complicated where calculations and assumptions need to be made. Category C data is the data which can be found relevant for simulation purposes but is not yet collectable, thus not available and not collectable.

2.2.3 Data Processing

Data processing refers to the transformation and analysis of raw data into useful information for the simulation model (Davenport and Prusak 1998). Skoogh and Johansson (2008) state that the output of data collection activities is already pre-analyzed data and/or sets of raw data, and that the analysis effort is considerably larger in samples of data describing variability than in those with only constant data. According to Robinson (2004) variability in data could be represented using one out of four options: traces, empirical distributions, bootstrapping, or statistical distributions; where empirical and statistical distributions are the most typical representations in DES software applications. For this reason, the data processing step should aim to generate simulation model input parameters which satisfy a valid representation of the collected data.

Data processing is a time-consuming task according to Skoogh and Johansson (2007), because it requires knowledge about the quality of both the collected data and the required parameters format that are needed as input for the simulation model. The user is responsible to validate the result, and if it is found not significant then more data need to be collected. To address this issue the thesis refers to the activities required for transforming data into information developed by Davenport and Prusak (1998):

1. Contextualization Knowledge about what purpose the data were collected for.
2. Categorization Knowledge about units of analysis or key components of the data.

3. Correction — Removal of errors from the data.
4. Calculation — Mathematical calculations or statistical analysis of the data.
5. Condensation — Summarizing of the data in a more concise form.

From the simulator point of view it is important to have the best representation of reality in the form of input parameters for the simulation model. Some simulation software applications include statistical tools to analyze and extract the parameters for the simulation out of the data sample. Additional adaptations of the data must be performed previously in order for the statistical tool to read the sample in the correct units. As mentioned by Robinson (2004), statistical or empirical distributions are most common because they condense the data set to a convenient size.

Several researchers have agreed on a process on how to go from raw data to statistical distributions. It has been divided in four steps, Banks, Carson, and Nelson (1996); Pedgen, Shannon, and Sadowski (1995); Leemis (2004):

1. Evaluating the basic characteristics of the empirical data set.
2. Select distribution families for evaluation.
3. Select the best-fitting parameter values for all chosen distribution families.
4. Determine the "goodness-of-fit" and select the best distribution.

Contextualization and Categorization

In order to start processing the raw data a good starting point would be to replicate Davenport and Prusak (1998) approach and both contextualize and categorize the data set to know its purpose, reason for being collected, and characteristics about its form. To help with this task, the data set can be classified into probabilistic or deterministic, and discrete or continuous:

> *Deterministic Input Data* – Occurrence of data in a predictable manner each time, e.g. preventative maintenance intervals, conveyor velocities, Chung (2004).
>
> *Probabilistic Input Data* – A process which does not occur with regularity and does not follow an exact known behavior, e.g. inter-arrival times, repair times, Chung (2004).
>
> *Discrete Data* – Can only take certain values, usually a whole number. E.g. number of products processed before machine breakdown, Chung (2004).
>
> *Continuous Data* – Can take any value in an observed range, e.g. time between arrivals, service times, Chung (2004).

Correction: Quality of Data

In the Input Data Management methodology proposed by Skoogh and Johansson (2008), data accuracy requirements must be established before available data identification or any data collection is performed. As consequence a gap is generated between the available data and the simulation requirements, which defines the quality of the collected data. Having poor data availability is the major reason for pitfalls in input data collection according to Perera and Liyanage (2000). Perrica et al. (2008), state that the amount of samples that must be taken into consideration to estimate probability functions should be at least 230. Skoogh and Johansson (2008) agree that this estimation can be used as a good rule of thumb for most parameters. It has also been proven by Skoogh et al. (2012) that it is possible to automate the extraction and correction of data in cases where the correction actions are a repetitive task. Nevertheless, when the quality of data is inconsistent at each collection event it is difficult to automate the data processing and utilize automation tools like the GDM-Tool proposed by Skoogh et al. (2012), which becomes unfeasible.

Calculation: Statistical analysis

After the first three steps of data collection, quality evaluation, and correction have been done, the available quantitative samples need to be statistically analyzed and be described through statistical functions. The use of empirical data in the simulation model should be avoided because it lacks unobserved data in the system, which is covered by the tails of the statistical functions.

According to Chung (2004) data can be found not only in production data bases or systems, but also from manufacturing specifications, operator or manager estimates. This empirical data can be used as a first estimate in a triangular distribution; with shortest, longest and most common processing times for a particular operation, to get an idea over the production situation. However, caution need to be taken here as the data collector wants unbiased data without disruptions in the process. Operators under observance might speed up or lower their work rate, which causes inaccuracy in the data input. All data from the theoretical distribution can be used to run the simulation model successfully with a more realistic result than by only using the observed data sample, Chung (2004).

The quantitative collected data can be used directly in simulation software packages, such as Siemens Plant Simulation™ or Rockwell Arena ™, as the programs also have integrated statistical analysis tools, which can handle calculations automatically and clearly display the results to the modeler. Other purely statistical software packages, like Minitab ™ or ExpertFit™, can also be useful for simulation study purposes. Leemis (2004) present a manual input modeling method for data calculation, which resembles the process performed automatically by the mentioned software packages, accordingly:

- Assess sample independency
- Chose distribution families to evaluate
- Estimate parameters (Maximum Likelihood Estimator)
- Assess model adequacy (goodness-of-fit test)
- Visualize the model adequacy (P-P or Q-Q plots)

Chung (2004) divides probability distributions types in two groups, more common and less common for simulation modeling purpose. See *Table 3*.

Bernoulli distribution

The Bernoulli distribution indicates a random occurrence with one of two possible outcomes, often referred as success or failure rate. It is defined as:

$$mean = p \quad (1)$$

$$var. = p(1-p) \quad (2)$$

Where p is the fraction of success and $(1-p)$ is the fraction of failures

Some examples of Bernoulli distribution in DES modeling are:

- Pass/fail inspection processes

- First class vs. coach passengers
- Rush vs. regular priority orders

Table 3 Statistical distribution functions in DES

Most common distribution functions		Less common distribution functions	
Name	**Parameters**	**Name**	**Parameters**
Bernoulli	Probability of occurrence	**Beta**	Shape, Scale
Uniform	Start , Stop	**Gamma**	Shape, Scale
Exponential	Average of sample data	**Weibull**	Shape, Scale
Normal	Mean, Std. Deviation		
Triangular	Minimum, Maximum, Mode		

Uniform distribution

In the uniform probability function, the entire range of possible values has the same probability of occurrence. It is defined as:

$$mean = \frac{(a+b)}{2} \tag{3}$$

$$var. = \frac{(b-a)^2}{12} \tag{4}$$

Where a is the minimum and b is the maximum value

Exponential distribution

The number of observations continuously decreases as the inter-arrival time increases. The statistical equations for the mean and variance of the exponential distribution are:

$$mean = B \tag{5}$$

$$var = B^2 \tag{6}$$

Probability is represented by:

$$f(x) = \frac{1}{B}e^{-x} \tag{7}$$

Some example processes are:

- Intervals of machine breakdowns or failures
- Arrival of orders

Normal distribution

Due to the nature of normal distribution and its variance, the simulation modeler must be careful if values generated by a normal distribution can be negative or not, e.g. process time. The function for normal distribution probability is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \qquad (8)$$

Where μ is the mean and σ the standard deviation.

Triangular distribution

When there is no complete knowledge about a process, but where the modeler suspects a normal distribution behavior, the triangular distribution is a very good first approximation. It is also useful for data with small deviations. The triangular distribution utilizes mean and variance values accordingly:

$$mean = \frac{a+m+b}{3} \qquad (9)$$

$$var. = \frac{(a^2+m^2+b^2-ma-ab-mb)}{18} \qquad (10)$$

Where a is the minimum, m is the mode, and b is the maximum value.

Some examples of triangular distribution use are:

- Robotic operations
- Manufacturing processing time
- Transport times

Condensation

The condensation task is related to the simulation software that is used by the model builder. Most frequently the common parameters that define the statistical functions are the ones needed to be fed into the software. Nevertheless, it is important to refer to the programmer´s guide for each of the simulation software packages in order to have an accurate format and make automation feasible. *Figure 6* shows a Normal distribution function parameter definition for Siemens Plant Simulation™.

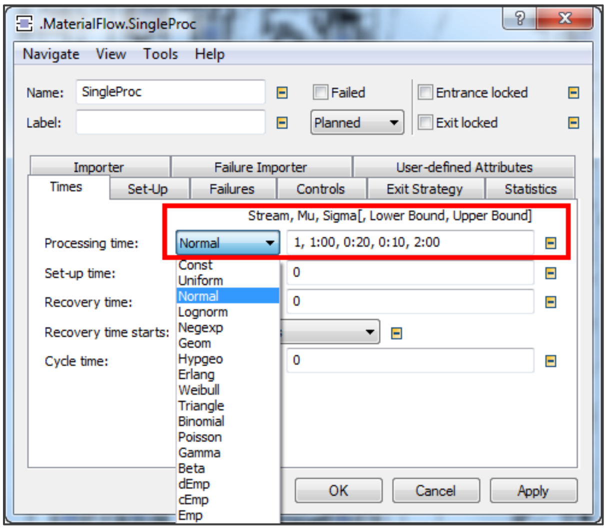


Figure 6 Statistical distribution parameters in Plant Simulation™

2.2.4 Interfacing

The collection of data is a repetitive method that is convenient to automate, Robertson and Perera (2002). Also the integration between different existing systems in an enterprise could benefit the organization. Some successful integration study cases point towards the development of a fully integrated environment that can autonomously update the parameters for the simulation.

Enterprise Resource Planner (ERP)

The ERP system has potential to become a widely useful tool in organizations. That is if the other organizational subsystems can be directly linked to the ERP. There are two main approaches in how companies solve this issue, Slack and Lewis (2011). The first approach is to change the other subsystems within the organization, at the same time as the ERP is implemented, to fit the chosen ERP. The second approach is to adapt current subsystems to the new ERP by implementing internal changes. The latter option is perhaps less expensive but can yield in connection issues.

Moon and Phtak (2005) presents a study case where MRP functionality of the ERP system is integrated through bi-directional feedback to a simulation model that can estimate shortcomings and unrealistic lead times, thus enhancing the ERP´s system functionality with DES. This integration involves a pre-built simulation model, and certain judgment actions on the results, but emphasizes the population of data from the ERP system into the Simulation.

MS Excel™

Many times a standardized format is required to be readable by the simulation model (Robertson and Perera, 2002); certain formats must meet requirements by the import script in the simulation model in order to use the data. MS Excel™ is not only one of the most popular IT tools but also a very good resource to visualize databases and monitor the contents of such collected data. When the data requires some adaptation it is more likely that more people would be able to work on processing the data. It serves most of the occasions as intermediary database between the simulation tool and the actual collected information due to its visualization and ease of use capabilities.

XML and CMSD

Standardization is one of the main elements of Lean Manufacturing, according to Liker (2006), to increase efficiency and continuous improvements. In simulation it can also mean compatibility between different kinds of software and vendors and facilitate the exchange of information. One of the most common standardized formats to exchange information between existing manufacturing systems is eXtensible Markup Language (XML), and for the specific case of DES projects a standard called Core Manufacturing Simulation Data (CMSD) has been developed within the simulation interoperability standards organization (SISO). As referred by Fournier (2011), the CMSD specification provides a standard XML (Microsoft 2011) file format for representing a manufacturing´s system data (see *Figure 7*) and it has been proven, at least partially, to be an effective method to build a simulation model automatically by means of translators for different DES software brands. Bergmann, et al.(2011) have also developed a prototypical implementation of a CMSD based model generator in Siemens Plant Simulation™, that represents a viable approach towards cyclic model generation that could facilitate the adaptation of the model to the real system changes, facilitating research work for RQ2 to automatically update the model.

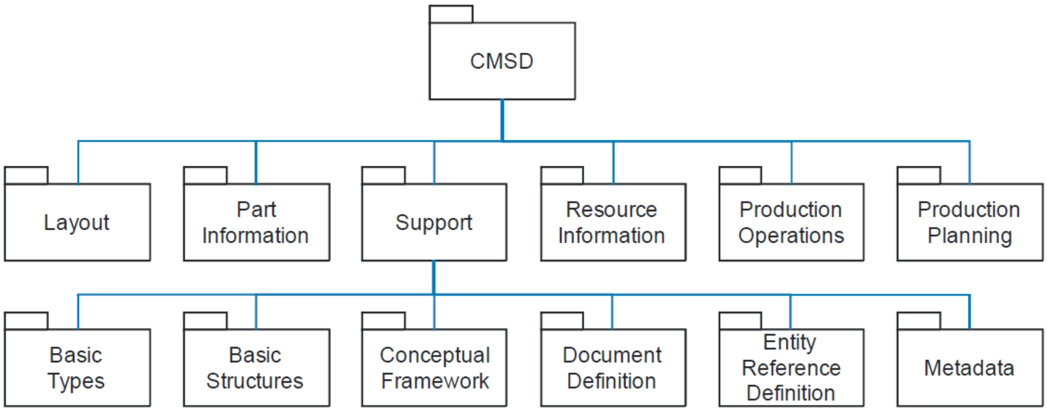


Figure 7 The packages of the CMSD Information Model (SISO 2010)

2.2.5 Data input methodologies

Robertson and Perera (2002) have identified four different types of methods used in companies today when collecting data for simulation projects, see *Figure 8*.

Methodology A

Raw data is collected and inserted manually into the simulation model by the model builder. Data sources are typically shop-floor processes, software and surveys. The approach is simplistic with the benefit of allowing less experienced model builders to perform the job. The manual parts are often very time consuming and need to be verified by the model builder, which makes the approach less desirable.

Methodology B

The main difference when comparing methodology B with A is that the direct manual data input is replaced with an external spreadsheet. The validation process thus becomes much easier and data can be manipulated before being inserted in the model. The model can be run without specific experience or knowledge in simulation model building.

Methodology C

Methodology C takes advantage of existing systems as data storage sources by connecting them with the simulation to enable automatic updates, instead of using for instance storage in a spreadsheet. Methodology C is easy to use with the possibility to perform test scenarios and because it is automated it diminish the time consumption.

Methodology D

Methodology D is taking the input data automatically from the production processes by using for instance ERP systems within the company. The time and work efforts get reduced drastically but the process of building the simulation model becomes much more complex. This approach requires experienced model builders with great specific knowledge. Another drawback is the lack of compiled data within the company systems. Studies by Skoogh and Johansson (2012) shows that only around 7 percent of companies have the necessary data available at simulation project start.

Further investigations of the data gathering process has been done by Skoogh and Johansson (2009) through case studies of DES projects in Nordic companies. In their research they found that the actual data collection represented 50 percent of the total time. This was because most companies still use methodology A with manual data input, due to its easiness of use.

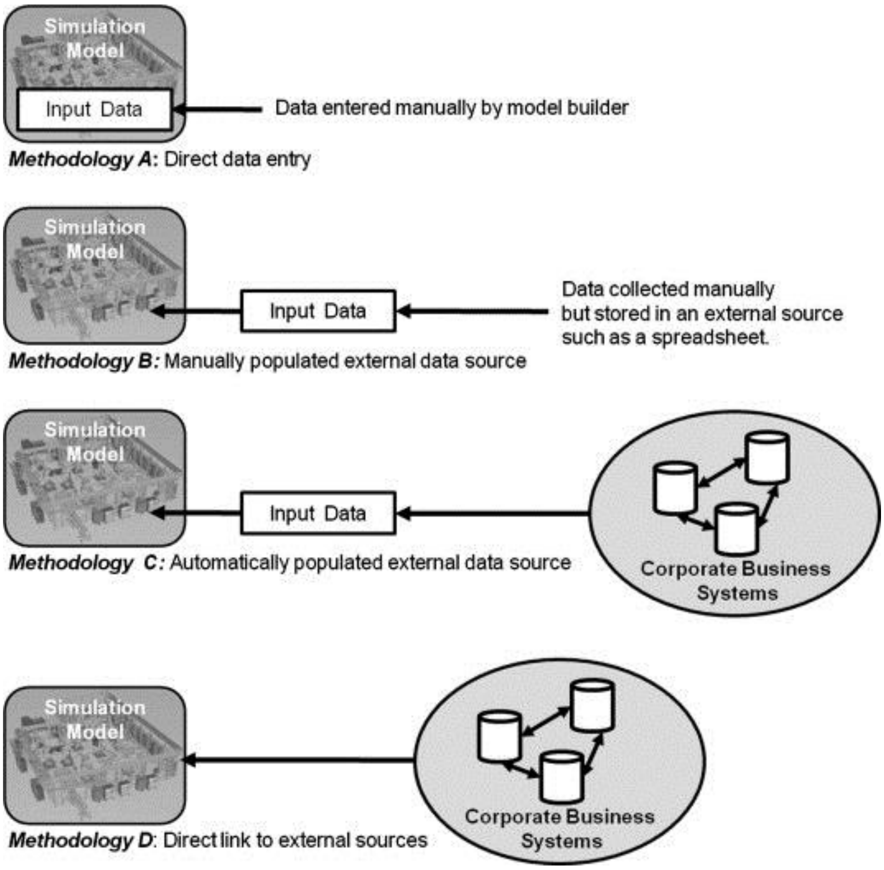


Figure 8 Data input methodologies A, B, C, and D (Robertson and Perera, 2002).

2.3 Supporting Tools in Simulation

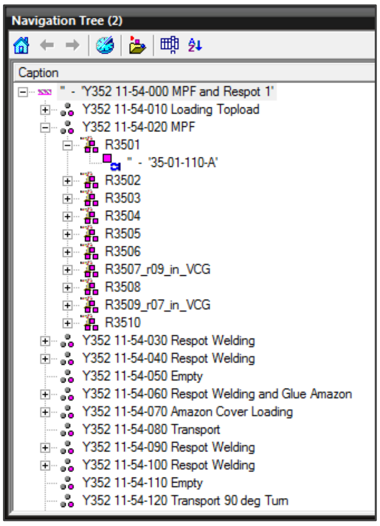
As mentioned in the previous section, information sources might be required to interface with other systems that manage information in the organization. Some of these systems serve a special purpose at planning or production stages and for the purpose of this thesis the most relevant are described in detail.

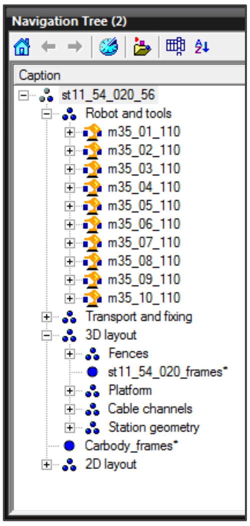
2.3.1 Manufacturing Engineering Planning Software - Process Designer™

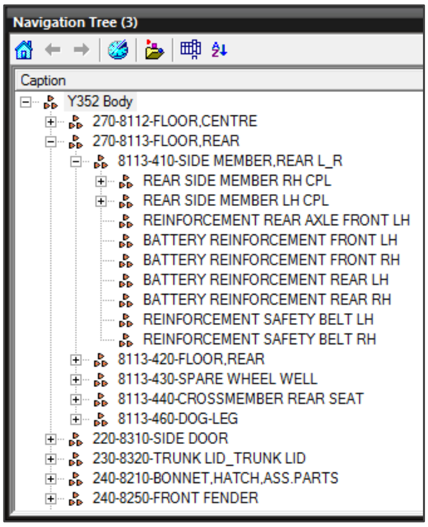
At production planning stage, assumptions on many input parameters are done because there is no historical information available. Generally an early rough validation of throughput for the sequence of operations, resources used, and product, is enough for a simulation model delivery at this point in time. Nevertheless, if the process information is organized in a structured way in the planning software and if updated with the latest changes and performance of the running line it can be also very useful for later stages.

Process designer is an engineering planning application developed by Siemens PLM Software, which main objective is to generate an electronic Bill of Processes (eBOP). The eBOP defines the sequence of processes or operations performed in the factory and relate the specific product and resources that will be used to perform the operation. Furthermore it can organize and relate manufacturing features (spot welds, weld seams and similar) to the product and the operations. It organizes the information on structured trees and object libraries, which enable several advantages regarding 3D visualization and re-use.

The three main structures that compose the eBOP in Process Designer are: the operation tree, the resource tree and the product tree (see *(Left) Figure* ***9***,*(Center) Figure* ***10***, *(Right) Figure* ***11***). The operation tree shows the sequence of operations, their processing times, and if a part of the product is consumed at each operation. A specific station operation object is related to a specific station resource object that contains the resources in which the operation is performed. The product tree is a structure that shows how the product is composed and represents the Bill of Materials (BOM) arranged in a manufacturing structure that fits to the structure of the processes; for example, a certain pre-assembled product part would display as a single object. Finally, resource tree structure what objects compose each of the plants/lines/stations where the process is performed. It represents the Bill of Resources (BOR) arranged in a specific structure that resembles the actual plant layout.







(Left) Figure 9 Operation tree Y352 11-541-000 MPF and Respot

(Center) Figure 10 Resource tree st11_54_020_56

(Right) Figure 11 Product tree Y352 Body

Since several types of products and variants can be processed in the same station, and sometimes, different processes and resources are required for each different product then several relations between the Resources tree, Product tree and Operation Tree may exist. Each relation can be done through "Studies" inside Process Designer. A Study object would delimit the application to display and work on a specific product variant, specific section of the plant, and a specific operation for that product. By having this delimitation the software knows which 3D objects and what object information is required to load in order for the manufacturing engineer to work.

There are several tasks that can be performed with Process Designer, for example:

- Consuming the eBOM (Engineering Bill of Materials) according to the manufacturing arrangement to make sure that every part or assembly of the product has been used (consumed) at a certain process.
- Relating the resources available (BOR) at the Plant to be used in the process and use 3D visualization capabilities.
- Visualization of the process flow through PERT charts, Gantt charts, tables, and in the structure trees.

2.3.2 Layout design software – AutoCAD™

When a simulation model is created, the stations and transport systems need to be located in a space that replicates the current production layout, and one of the most common industry software tools for layout design is Autodesk AutoCAD ™. It is a drawing software application specially made for facilities and construction engineering purposes. The common outputs of this tool are 2D blueprint files that are easy to explore and manage. For simulation purposes, the AutoCAD ™ layout drawing is often a good starting point to look into and understand the construction of the studied system. It also provides good guidance on the exact location of the resources within the physical space and in many times contain useful visual information about the material or production flow.

2.3.3 Product Data Management – Teamcenter™

In large engineering enterprises there is a need to manage complexity in products that a Product Data Management (PDM) system can handle (Siemens PLM Software, 2014). A PDM system allows the engineers to create parts through a structured engineering process workflow. Increased complexity in a product (variants, changes, revisions and releases) and collaboration between different departments of an organization are one of the keys for engineering firms to succeed. A PDM allows having a unique source of information for all the members of an organization where all the latest changes are immediately visible. It also contains powerful visualization tools and integration with the most common CAx applications like Catia ™ or NX™. One of the main purposes of the PDM is to structure the product in an Engineering Bill of Material (EBOM) organized in functional groups. This structure is commonly exported, sent forward to, and rearranged in the manufacturing planning application, such as Process Designer ™ transforming the structure of the EBOM into a new one typically called Manufacturing Bill of Materials (MBOM).

2.3.4 Statistical Analysis software – Minitab™

As shown in 2.1, as part of the simulation project methodology, data collection has shown to be significantly time-consuming, having a neat process of input data management becomes crucial to the effectiveness of the project (refer further in section 2.2) . It is required that the data collected from the available systems is processed into useful information, as mentioned in section *Data Processing*. The data processing step in the Input Data Management process could be performed by a third party application or inside the simulation software. One of the most common industry practices is to process the sets of data inside MS Excel ™ spreadsheets, or use more advanced statistical tools such as Minitab ™ to condense the data into statistical distribution functions, which in turn can be fed into the simulation model.

MS Excel™ provides the user with the regular capabilities found in statistical software while having the advantage of their extensive user base and knowledge accessibility. If the installed functionalities are not sufficient the user can create Macros that enhance the automation capabilities of processing data through Visual Basic ™ scripts.

Minitab™ is a specialized statistical software with advanced tools for statistical analyses. Even if the user base is relatively low, its ease of use is high and visualization of results more intuitive.

2.4 Risk Assessment in Data Input for Simulation

The data collection process can involve several potential risks which should be considered before using in a simulation project. Common risks are touched upon below.

Correctness – Wrong labeling and identification of data or embedded technical problems can raise issues related to correctness, Skoogh et al. (2012).

Completeness – The data cannot be found in existing sources, Skoogh et al. (2012).

Duplication - Several different sources can provide the same data item. The data source providing the most accurate data should preferably be chosen here, Robertson and Perera (2002). Another word used to refer to this issue is consistency, Skoogh et al. (2012).

Accuracy, Reliability and Validity – Data collected must always be verified to be accurate, reliable and valid before being used as input in a simulation model, Robertson and Perera (2002). Specifically accuracy has to do with the investigated sources and format of data, Skoogh et al. (2012). Description of the current state including latest changes has to do with the validity, Skoogh et al. (2012). As mentioned previously the output of the simulation model will not be accurate and cannot be trusted.

Timeliness **-** Typically data is collected from a wide range of sources. This can create an issue of connected data being available at different times. The data collection process may become iterative due to this where the modeler needs to connect the data sources when data is available, Robertson and Perera (2002).

Historical **-** Considering usage of historical records for data collection may need some consideration due to risks, Chung (2004). Firstly the production system could be changed within the time period which the data is collected from. A simulation, using this type of inaccurate data, will end up with incorrect predictions and cannot be validated. Another issue which can arise from usage of historical data is the lack of needed data, something which might not be realized until late in the simulation project.

2.5 Design of Experiments

In the experimental phase of the simulation project Design of experiments (DOE) can be used successfully, Banks (1998). Plant Simulation™ has an inbuilt feature using DOE called the Experimental Manager. In order to fully take advantage of the tool some background knowledge is essential. In this section the DOE method will be explained on a deeper level to point a direction of research and name useful tools to analyze the results of a common simulation case study.

2.5.1 Introduction to DOE

To determine which resources (such as equipment tools, conveyors etc.) and settings which have the most influence on the process performance a set of experiments is made, thus enabling changes towards a more optimal performance. DOE is an efficient methodology of performing several experiments at the same time, Montgomery (2000). The aim of a DOE is to use a minimum of resources for a maximum of information, which implies several factors with a smaller number of samples, Cavazzuti (2013), Bergman and Klefsjö (2010). This reduces the cost compared to using the one-factor-at-a-time experiment, Bergman and Klefsjö (2010). The following DOEs are presented in below sections:

- Full factorial design
- Fractional factorial design

Explanation below relates to terms that are of interest and importance when investigating DOE, Cavazzuti (2013).

Noise is the term used for errors in DOE. Statistical methods are used to diminish the effects on the results caused by noise. General groupings of these statistical methods are randomization, replication and blocking, Cavazzuti (2013), Bergman and Klefsjö (2010).

Randomization concerns the order that the experimental runs are made. The order is randomized to remove potential influence from the previous to the following or potential ability to predict experimental results.

Replication is used to duplicate a specific setting in order to be able to run that setting several times. This is done to verify quality and correctness.

Blocking is used for isolation of events which are disrupting the experimental main result. These events can thus be blocked out and their effects can thereby be prevented.

2.5.2 Full factorial design

Creating a test plan before the experiments is started also yields in lower costs, Bergman and Klefsjö (2010). A *full factorial design* utilizes this strategy with a plan that includes which *factors* to be studied, such as:

- Buffer size
- Station throughput time
- Product mix

Table 4 Design matrix from Bergman and Klefsjö (2010)

Run no.	Main factors and interaction							
	A	B	C	AxB	AxC	BxC	AxBxC	y
1	-	-	-	+	+	+	-	67
2	+	-	-	-	-	+	+	79
3	-	+	-	-	+	-	+	59
4	+	+	-	+	-	-	-	90
5	-	-	+	+	-	-	+	61
6	+	-	+	-	+	-	-	75
7	-	+	+	-	-	+	-	52
8	+	+	+	+	+	+	+	87
Estimated effects	23	1.5	-5.0	10	1.5	0.0	0.5	

Then the two *levels* are decided on and set for each factor, one high and one low value. The high value corresponds to a "+" and the low to a "-". The experiment then *runs* for each test condition in a *randomized* order with, as in this case of three factors, eight runs. Estimation on the effects of the experiment can be assessed using the average of the difference in high and low values. By performing experiments like this the interaction of factors can be identified, an effect which is not possible to estimate when performing a one-test-at-a-time experiment. Estimated effects are then presented in a design matrix (see *Table 4*) where a clear visualization provides an immediate overview of factor impact and in between interaction.

2.5.3 Fractional factorial design

In the case when three factors are investigated, and two of the factors A and B do not interact, a fractional factorial design can be performed. This yield in even lower resource utilization as fewer runs needs to be performed to see the interaction on factors A and B by the factor C. In a scenario with three factors only four runs are needed. If the A and B factors would have had interaction they would have said to *aliased* and a full factorial design would have been necessary. Fractional factorial design can be extended to more factors where there are reason to think only two factors actually interact, Bergman and Klefsjö (2010).

2.5.4 Statistical process control

Statistical process control (SPC) is implemented to find assignable causes of variation in order to eliminate them to stabilize and perform supervision of processes, by taking a sample of observation at certain time intervals. Found causes are either *assignable,* and can be directly linked as a major contributor to variation, or *common*, which are more general cause contributors to variation. When a process is in statistical control the standard deviation and mean are known. The process is then stable and the quality indicator are within calculated limits e.g. *control limits*. For further depth in the SPC subject see Bergman and Klefsjö (2010).

An example of DOE experimental design with two processes follows based on an introduction chapter by Goos and Jones (2011).

Sample size: n

Mean: μ_1, μ_2

Average: $\overline{x}_1,\ \overline{x}_2$

Standard deviation: $\sigma_{\overline{x}_1-\overline{x}_2} = \sqrt{\frac{\sigma^2}{n_1}+\frac{\sigma^2}{n_2}}$

Variance: $\frac{\sigma^2}{n_1}, \frac{\sigma^2}{n_2},$

The processes could for instance be two machines performing the same operation but having different average and mean in outcome. The variance differences could as an example depend on differences in length, thickness etc. of the produced output. *Table 5* shows an example of the DOE representation with $\sigma^2 = 1$.

Table 5 Design of experiments example with two samples, directly from Goos and Jones (2011)

n_1	n_2	Var($\bar{x}_1 - \bar{x}_2$)	$\sigma_{\bar{x}_1 - \bar{x}_2}$	Efficiency (%)
1	11	1.091	1.044	30.6
2	10	0.600	0.775	55.6
3	9	0.444	0.667	75.0
4	8	0.375	0.612	88.9
5	7	0.343	0.586	97.2
6	6	0.333	0.577	100.0
7	5	0.343	0.586	97.2
8	4	0.375	0.612	88.9
9	3	0.444	0.667	75.0
10	2	0.600	0.755	55.6
11	2	1.091	1.044	30.6

3 Methodology

Focus on the thesis lies within the data collection process in order to perform a gap analysis in VCT. According to the thesis purpose, the main objective of the gap analysis is to create a foundation, which supports a future automation of simulation models through the StreaMod project. To understand what the simulation requirements are, a simulation model is set up on the area of the project scope. The methodology for the general simulation model creation is based on the theory described in section 2.1 and 2.2, and goes into depth for the input data management.

According to Banks simulation project methodology a simulation project was started. Focus was mainly on the iterative process between the conceptual model and the data gathering. Special attention was given to the data collection process and general input data management, see *Figure 12*, which is described further in the following section, 3.1 Input Data Management Methodology.

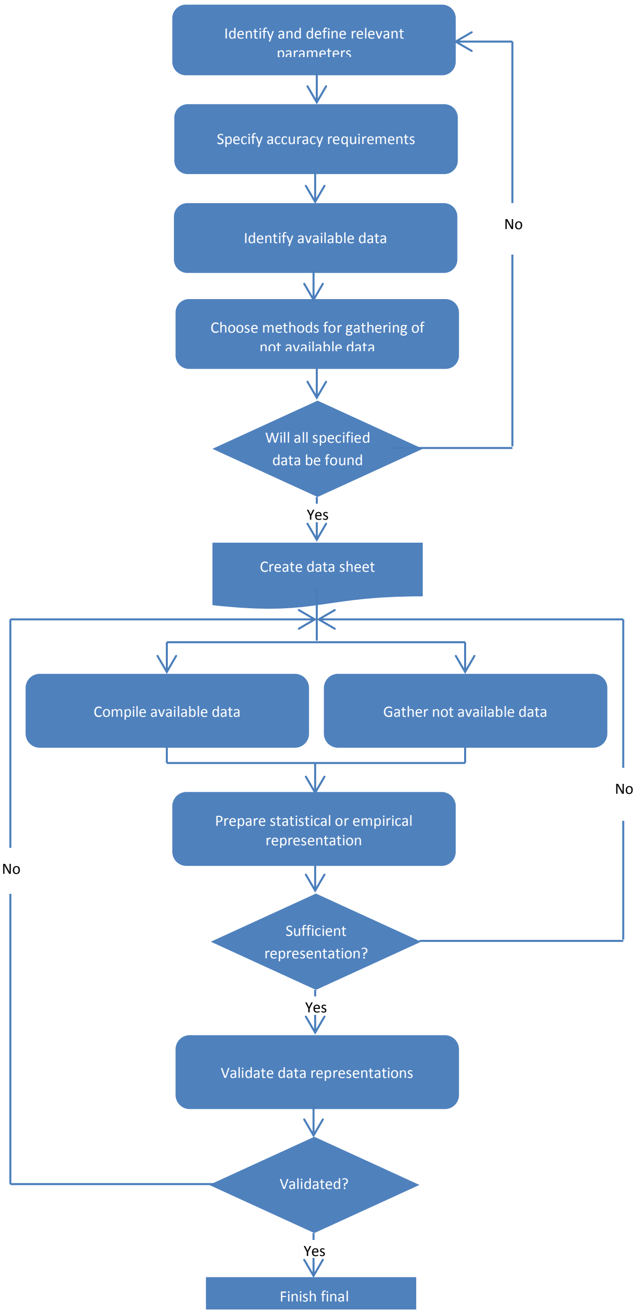


Figure 12 Input data management methodology, Skoogh and Johansson (2008)

3.1 Input Data Management Methodology

As describe in the Theory chapter the thesis is outlined accordingly:

1. Identify and define relevant parameters
2. Specify accuracy requirements
3. Identify available data
4. Choose methods for gathering of not available data

- Milestone: Will all specified data be found?

5. Create data sheet
6. Compile available data
7. Gather not available data
8. Prepare statistical or empirical representation

- Milestone: Sufficient representation?

9. Validate data representations

- Milestone: Validated?

10. Finish final documentation

3.1.1 Identify and define relevant parameters: What data and information is needed to enable the creation of automatic simulation

Interviews were held with responsible persons to outline which programs and databases that are used and a rough estimation of what information they contain. A conceptual model was also created in order to more clearly overview requirements for the DES. Based on the findings the desired parameters were set to enable a first draft of the simulation model. Needed parameters included:

- Processing time [s]
- Transportation time [s]
- Disturbances related to failure, duration [s] and interval between failures [s]
- Product mix [Body type]
- Layout
- Steering logic
- Transportation equipment [quantity]

3.1.2 Specify accuracy requirements: Quality of input data

Based on the theory presented in chapter 0 the lower limit of collected data were decided to be 200 samples, and with the desired data collection to be around 230 samples. A larger sample size was decided to be acceptable as the amount of work in gathering the data could be neglected compared to using a smaller sample size. The 200 samples was mainly a lower limit for the disturbances at station level without concern to product type.

At this step factory visits provided understanding of the processes to be modeled, critical areas and estimation in level of importance of parameters. The quality of the category A data was investigated to enable a trustworthy final result for the simulation and also to be able to provide accurate results on the gap analysis of data relating to discrete event simulation. At this step a video analysis of Line-54 was also made. A comparison was made between observed times and system logged processing and disturbance times.

Statistical methods were used for samples showing a good estimation with data fit. With the assumption that the processing time is consistent, and only fluctuating with a few seconds for each body type, the triangular distribution was used. For failures the data fit was the decided to approximate the most appropriate statistical method to be used. Finally, in cases of poor data fit the empirical distribution should be used taking random values within the data set.

3.1.3 Identify available data: Mapping of data sources within Volvo Cars

A mapping of the combined CBS systems was the third step taken according to the chosen methodology by Skoogh and Johansson (2010). Based on the set criteria, in the previous steps, several data sources were identified as relevant category A data input:

- CTview
- SUSA
- TAP
- TATS

Where CTview and SUSA are data sources applications, TAP is the MES deciding product sequence, and TATS is an internal unofficial SCADA production website. CTview provided history data for transport and processing times combined with product mix. Disturbances with classification were found in SUSA. TAP provided production sequence and buffer numbers. TATS distributed information about buffer sizes, mainly in form of pictures. An overview is shown below in Figure 13. For more detailed information about the databases see Appendix A-C.

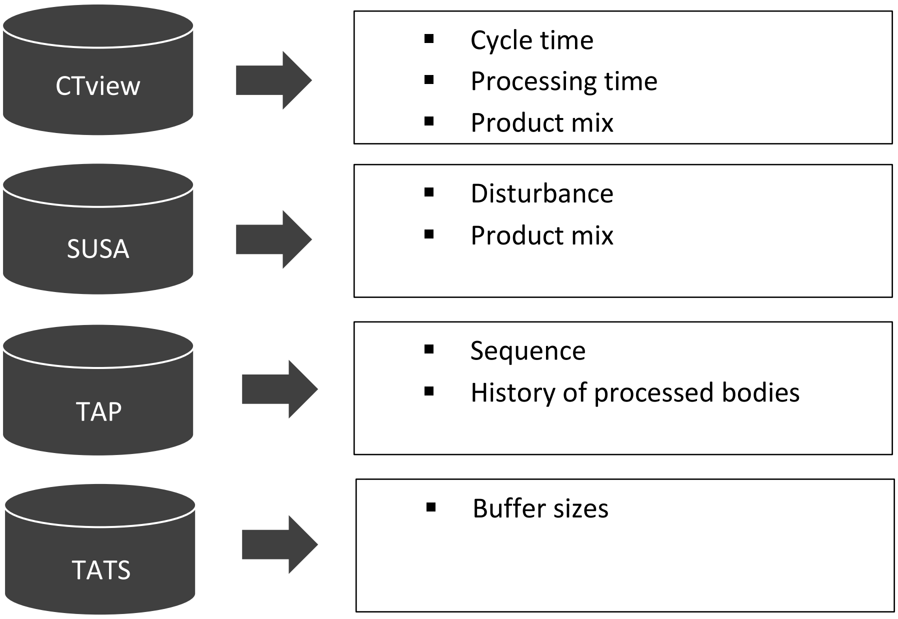


Figure 13 Overview of VCT databases

3.1.4 Choose methods for gathering not available data

Category B and C data was addressed at this step starting with a visual overview of unavailable and uncollectable data together with the available, see section 2.2 .

From the classification of category B data a plan was created based on manual attempts on how to extract and calculate the wanted information. Several program functions were investigated including AutoCAD™-drawings, MS Excel, Minitab, Mitsubishi's PLC, Process Designer, and Plant Simulation. This step included steering logic, layout, data quality, and general in-between lines transportation findings.

❖ **Milestone: Will all specified data be found?**

As a validation of the previous steps the question was asked and confirmed, although not all necessary data could be found directly, in order for the process to move on to step 5.

3.1.5 Create data sheet

Based on the characteristics of Plant simulation and available data format, data sheets were structured with consideration to previously defined parameters. All data was placed in the same folder with subfolders depending on content. Naming of data documents was standardized.

3.1.6 Compile available data

Data from SUSA was collected from week 1 to week 14 of year 2014. Due to shorter storage times for data in CTview, it could only be gathered from week 9 to week 14 of year 2014. Based on station and depending on data base source, Ctview or SUSA, the data was gathered in two specific folders. The reason to this was the idea of keeping the data transparent and clear to users outside of the thesis.

Two tailored macros for each database were created in order to speed up the data gathering process and making it more automated. By using the macros a conversion to a more usable time format was made. From these macros appropriate calculations and conversions, based on the defined parameters from the first step, was made such as clean cycle times, interval, duration etc.

For information which could not be found and downloaded to be used in MS Excel, there was only a process of collecting the data manually. However, as can be seen in the results in chapter 6 the performed gap analysis points out which information this was and where it can be found.

3.1.7 Gather not available data

Category B data was gathered and calculated by using production design programs such as Process Designer (PD) and AutoCAD™. The majority of the data found here was concerning transportation. Factory visits was another source which provided updated real time information mainly about buffer sizes, layout, and production steering logic. Accordingly the data found using these methods is presented as gap analysis results in chapter 6.

3.1.8 Prepare statistical or empirical representation

The data sheets created in Excel with data was organized to allow statistical evaluations with data fit within Plant Simulation. Based on the presented theory on statistical methods and general usage of data in DES, the different types of data were evaluated accordingly.

- ❖ **Milestone: Sufficient representation?**

Goodness-of-fit test were performed on the disturbance data. In cases where there was no data fit the empirical distribution was chosen as planned in the early steps. All data was questioned if having sufficient representation.

3.1.9 Validate data representations

A data validation process was made together with a simulation expert and by internal meetings where the data compilation process was explained thoroughly together with output and input format explanations. It was found that not all data could be validated to be sufficiently represented or with high enough quality.

- ❖ **Milestone: Validated?**

A systematic approach was utilized to confirm that all data representations had been questioned and verified as accurate or labeled otherwise. At this step it was clear that not all data could be validated to hold high enough quality for use in a simulation model.

3.1.10 Finish final documentation

Final documentation with examples of data sheets was finished and the gap analysis findings were added to the results in chapter 6, together with general results for the conceptual simulation model.

4 Simulation Model

The simulation model case of the Body Shop Factory was developed in order for the authors to understand what kind of information was needed and where it was extracted from, in the current production system. Findings regarding the different simulation input parameters used in the DES model creation, see *Figure 14*, are presented in this section. The results of the simulation model itself could be verified but not completely validated (Sargent, 2010), since it has been detected to hold a significant lack of quality regarding the data logged in the production database. Correcting the alarm and process times log is out of scope of the thesis but further discussed in Chapter 8 Discussion & Suggestions.

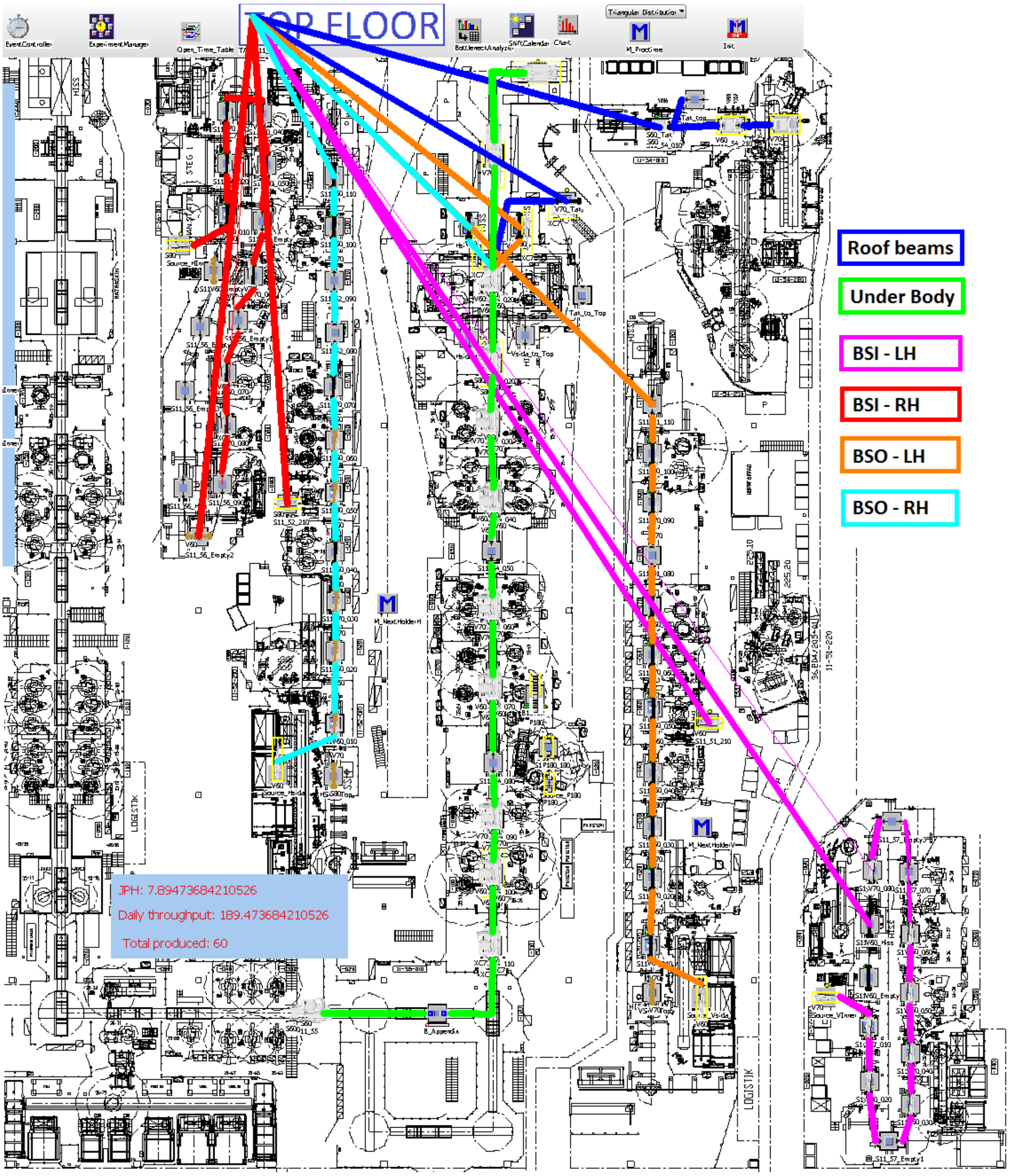


Figure 14 Simulation layout with Sankey Diagram for each line products

4.1 Empirical Data

After initial factory visits and introductions to the available production systems, the reliability of the logged production information seemed to be compromised by the most recent major changes. The thesis team decided to record production in stations of Line-54 at specific times, which involved the Framing station, and compare the logged data against what was observed in the videos. Several inconsistencies were found regarding alarms and processing times logged in information. The most relevant observation is that failure alarms cause problems with the processing times registers, for example it has been observed that when a robot has a technical failure in the middle of the process the registered processing time will include the duration of the failure.

4.2 Steering Logic

The steering logic defines how the material flows through the lines and what kind of conditions that must be true in order to pass the parts on to the next station and/or carry out certain additional actions. This was particularly relevant when modeling the logic at the BSI lines (11-56 and 11-57). In these lines, a product type specific fixture must match the production sequence and in case of a mismatch the Electric Overhead Monorail (EOM) elevator system must activate to change the current fixture for the correct one. In the simulation model the exit control at stations 11-(56/57)-Hiss (refer to Appendix D), and the predecessor station define the behavior of this logic along with the EOM exit strategy on the top floor. It has been detected that the logic differs on Left and Right sides mainly because the layout configuration and number of stations are different on each side.

This behavior of the production lines logic is described in the document “Driftanvisning” as mentioned in section 0. The pitfall, regarding documentation method for this specific case, is that even if the supplier updated the information, it is generally not always the case. Informal interviews with manufacturing engineers revealed uncertainty in the update validity of these documents. The most efficient resource that the authors used to understand the steering logic were factory visits and informal interviews with the people involved in the production lines. This last fact revealed unavailability of steering logic information in a system, which would be needed in order to automate a DES model creation.

4.3 Processing times

As explained in section 5 below, the Virtual Device contains the logged data about the processing times of the stations, whereas through CTview and/or TATS the team was able to collect logged data from week 9 to week 16 of 2014. In order to work with the logged processing times and get a more accurate representation of cycle times three possibilities were explored.

The first approach was to identify the failed cycle times by filtering all cycle times that last more than 90 seconds for each product type. This is already a common internal practice to obtain a quick representation of the cycle times that has shown fairly good results without consuming much time.

A second approach is a proposition that the authors came up with in order to obtain more accurate representations of cycle times. This approach filters the start-to-start cycle times that do not contain any kind of disturbance. This proposition is made assuming that three main conditions are always true. First, that the start-to-start cycle timestamps are triggered when a new product enters one station until the next product enters into the same one station. Second, that all kinds of disturbances; e.g. failures, starvations or blockages, registered in SUSA have a precise start timestamp. Third, that both of the logging systems are running under the same clock time.

With the use of a VBA script in MS Excel™ failures start timestamps could be located between the start-to-start timestamps and therefore those cycles that contain any failure could be identified and deleted. Additionally, the cycles out of regular working shifts were also deleted. The expected result is only cycles that contain pure processing time and transport times. Nevertheless, after applying this last method to the collected dataset, the resulting cycle times contained cycles that were longer than a clean cycle time expectation. This unexpected result means that some of other disturbances are not logged in the system or that the start timestamps are inaccurate.

The third approach is a combination of the first two approaches, which the thesis team believes would lead to the most accurate results possible.

4.4 Disturbances

The disturbances logged into SUSA are the largest issue regarding logged data, section 5.1.3. It has been found that the alarm monitoring resolution is very low, taking around 25 seconds for the VD to detect updates of a triggered alarm in the PLC´s. This can be one of the main causes of logging errors in disturbance durations since the alarms may overlap; e.g. when the operators enters inside a protected area to fix the failures might also trigger the door alarm.

Also as mentioned in section 4.1 on empirical data, there is an unclear definition of how the alarms affect processing times in the Virtual Device. The team considers logged disturbances as inaccurate information but assumed that the change of state (from normal to alarmed) timestamp is accurate for the simulation model creation.

4.5 Transport

The transport times between stations was included in the start-to-start cycle times, nevertheless several conveyor systems were modeled on top of the AutoCAD drawing. The conveyors that also acted as buffer places were undocumented and it was not possible to extract information out of the other software applications. The steering logic of the transport systems, for example the EOM at the BSO lines had a very complex behavior when the sequence of products was not stable and several fixture changes were required to cope with the correct sequence. Other discovery was that the left and the right side lines are different. The right hand side has more stations in the BSO line and more fixtures can be in the system, while the LH had fewer amount of fixtures.

5 Information map at VCT

To start answer RQ1 a mapping of the information sources at VCT is presented in this chapter grouped as: Input data source, Program software sources, and support information, see *Figure 15*. The chapter aims mainly at presenting the systems at VCT to make the reader more familiar with them.

RQ1 What are the requirements for input data to generate a simulation model that addresses a common engineering question?

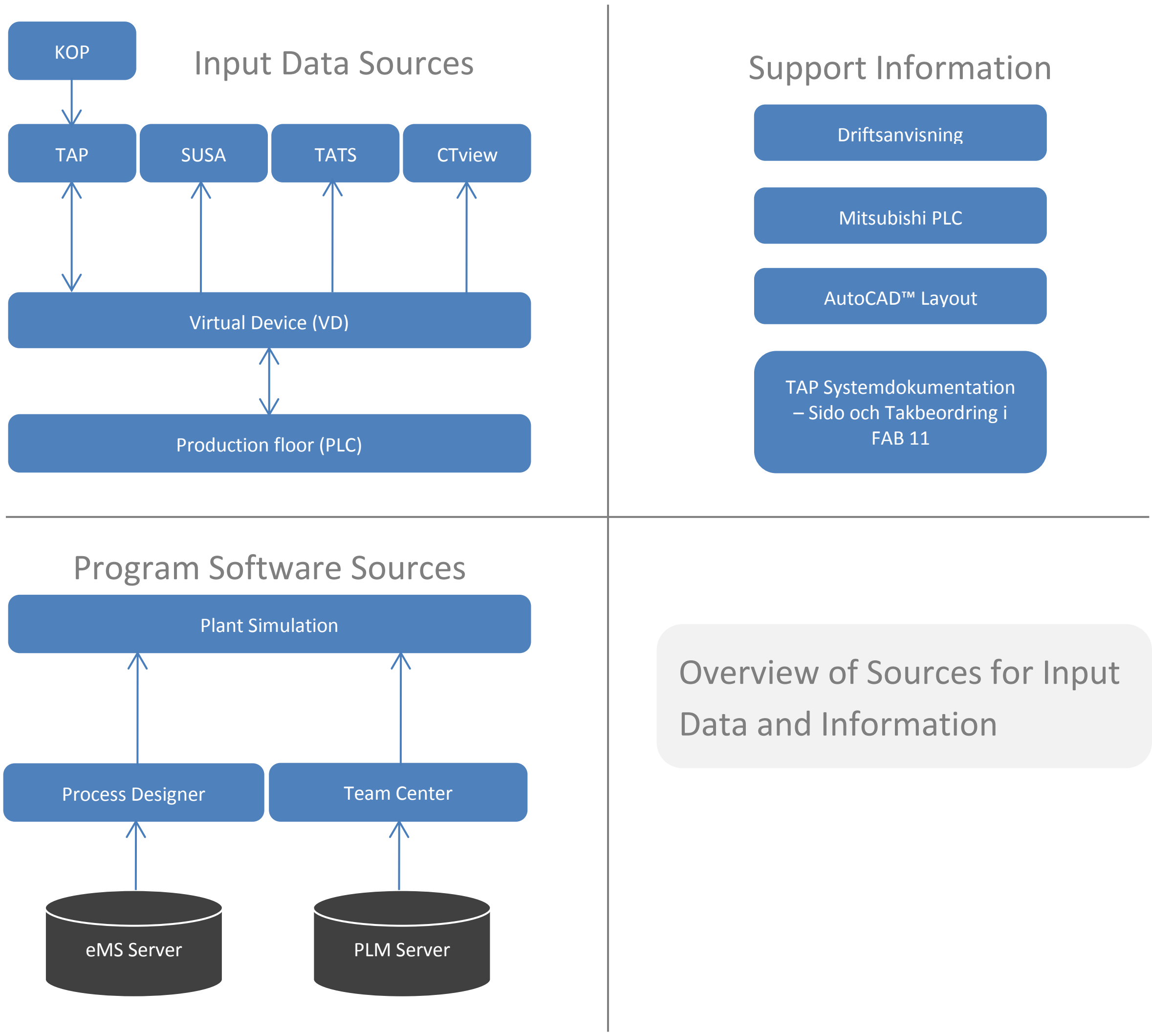


Figure 15 Information mapping of data and information sources at VCT

5.1 Input Data Sources

This section presents the findings regarding the actual production floor data sources, providing empirical real time data, which were explored and used when building the simulation model for the study case at VCT. All the data from the production lines PLC's is collected automatically through a system called Virtual Device (VD), then several applications can present the data in different ways to the user. Each section describes the purpose and data content of the applications that run over the VD.

5.1.1 TAP

TAP (Torslanda A-shop Planning software) is an application that manages all the product orders through the plant. Sequencing and ordering of body types are done through TAP. The user can track the location of a specific car body; find detailed information on timestamps at every station of the plant; specific car model; and historical production information. KOP system, which runs over TAP, is used by production planners to control orders in production.

5.1.2 CTview

CTview, also known as OEE Portal, is an application that runs over the Virtual Device that presents the collected data from the production floor in a database format that can be copied or exported into spreadsheets for further analysis, see *Figure 16*. The user can find different columns with information specific of a certain location of the factory, which contains all the timestamps of the products that have arrived to the station, the processing time, cycle time, transport time and processing time for each robot in the station. See Appendix A for instructions on how to use CTview.

CTview is a tool within the OEE portal that allows the user to get different registered times for a specific station in the plant. This information can be filtered, sorted or exported on-demand.

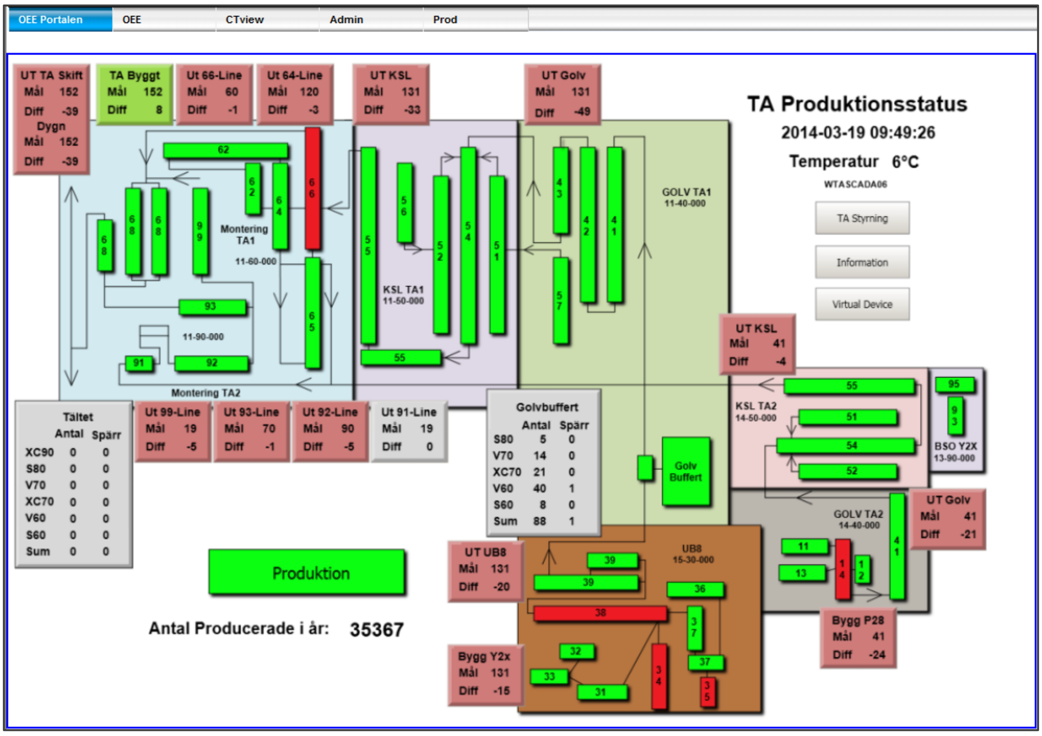


Figure 16 Body shop production in VCT

5.1.3 SUSA

SUSA is an application that registers all the disturbances in the factory. It classifies disturbances into different kinds and registers information about the body type, duration of disturbance and start/stop time of each failure. It can further filter the failures depending on type or data. See Appendix B for further instructions on how to use SUSA.

5.1.4 TATS

TATS is an unofficial SCADA website where production data is visualized. As CTview, TATS can display similar production data as well as buffer sizes and number of fixtures for the outer sides. It can also export around 45 days of production data directly to a MS Excel™ file, see Appendix C for further information.

5.2 Program Software Sources at VCT

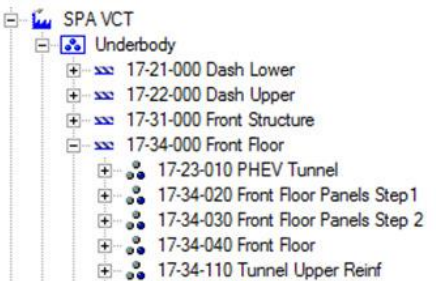
Process Designer™ is the software where VCT plan all the production processes at VCT, which could benefit the StreaMod project objectives. Secondly Teamcenter™, which is also a Siemens™ software, concentrates product information in a single source and has the potential to include manufacturing information in the future, addressing RQ2 in a longer term. This section present what kind of information, useful for the simulation modeler, can be found in each source at VCT.

5.2.1 Process Designer

As mentioned previously on section 2.3.1, Process Designer™ stores production planning information at VCT. The information that it contains is developed in collaboration with line builders. The requirements and specification of deliveries are standardized in a recently created document "VCC Manufacturing Simulation Specification".

Some usage characteristics of Process Designer at VCT are:

- One single Bill of Resources can be found in Process Designer containing the 3D CAD and resource tree structure available in the TA Plant. The tree structure and naming is standardized. *Figure 17* and *Figure 18* show an example of a standard resource tree.
- Additionally there is a specific BOP for each product type. Depending on the product variant, the process at each station may vary; therefore different BOPs are related to the Plant BOR.



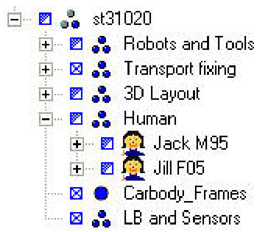


Figure 17 (Left) Resource tree in Process Designer

Figure 18 (Right) Resource tree at a deeper node level in Process Designer

After the BOP has been defined in Process Designer, the Station level robotics operations can be defined at Robot level. Process Simulate is used to generate all the paths and actions of process for all the robots in a station in order to create and validate virtually the process of the different car bodies. The objective of Process Simulate is to output the robot program that will be downloaded later to the robot.

Addressing RQ2, it has been explored by the thesis group the possibility to use the automatic export to a detailed simulation model that is apparently available in Process Designer™, nevertheless the versions of Plant Simulation™ that are supported are too old to be used and Siemens PLM Software™ has taken the decision to not further support this feature anymore, see *Figure 19*.

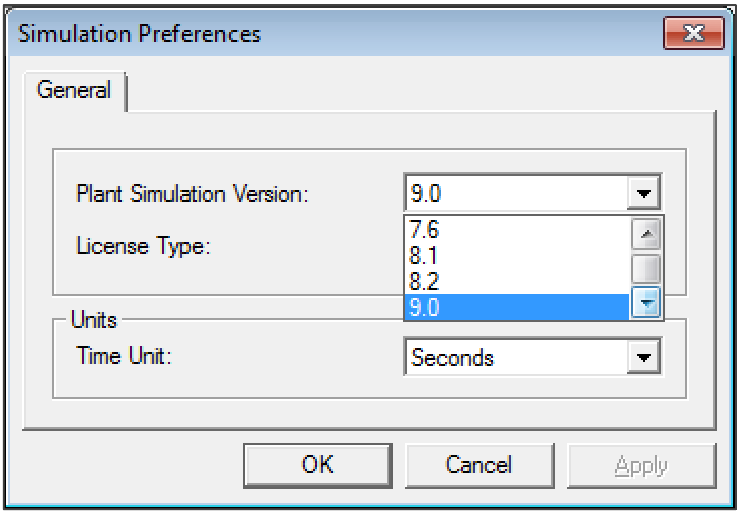


Figure 19 Simulation export only support until version 9.0 of Plant Simulation

For StreaMod project purpose, which deals with the possibility of automating the creation and update of simulation models, there are some characteristics from Process Designer that could tell the programmer of a script or the script designer what information could be extracted from it, especially the one regarding process, consumed parts and material flow without considering the transport systems. Some of these characteristics will be mentioned later on Chapter 6.

5.2.2 Teamcenter™

VCT uses Teamcenter™ to generate the BOM for each of the products including all variants and revisions that they might have. It contains a module called Manufacturing Process Planner, in which the user can setup a similar BOP as Process Designer does. Nevertheless, this has not been implemented in TA. The thesis team did not found relevant information in this source for a DES model and is not included in *Chapter 6* Gap Analysis. If in future the manufacturing module is implemented, then it would be interesting for RQ2.

5.3 Information Sources

Other sources of information that do not belong to any CBS or actual production data were explored and are presented in this section. These sources are found to be of possible relevance as support documentation and might be useful in the creation of a DES model.

5.3.1 Driftsanvisning

Driftsanvisning ("operating instructions" in English) is a manual that is delivered by the line builder, which provides written information about the order of value adding process steps for each station in a specific line. This kind of documents can be found in the organization VDOC system. It contains also a list of equipment for each of the stations in the line. The process descriptions are furthermore specified for each body type. The document is written in Swedish and is most similar to a description of the station operation.

5.3.2 Mitsubishi PLC

The steering logic of the production system, including transportation systems and alarms, in the TA factory is controlled by Mitsubishi™ PLCs. The thesis team explored the possibility to find useful information in the PLC programs or comments to model the steering logic. Inconveniently, the PLC programs required a high level of expertise in programming to understand the logic and the comments did not bring any value to the DES model creation. This possibility was disregarded and not further explored.

5.3.3 AutoCAD™ Layout

Other supporting tools for automotive industry are the layouts that the line builders design in order to build the equipment in place. One of the most common formats is to have an AutoCAD ™ drawing that contains the relevant equipment and surrounding objects that will be installed in the facilities. Many times equipment that is not directly part of the main processes are omitted in other systems, for example with transport of storage resources that do not add any value to the product but whose characteristics affect the production performance, the engineer can therefore extract dimensions and estimate capacities out of the drawings. At VCT AutoCAD™ is used for the production processes and displays stations. It is used as background pictures for DES projects within VCT and as an initial understanding of the process flow.

5.3.4 TAP Beordring

The ordering of products, such as sides, roof and body type, are described in the manual TAP beordring (“ordering” in English) which can be used as a complement to the TAP system. Here it is described from which station a signal is sent to initialize manufacturing start and how the products are queued. The production can therefore be said to be pull-based as products are only produced if there is a corresponding body type in upstream processes and thus a customer demand.

6 Gap Analysis

RQ2 How can a simulation model be integrated to the production data sources to automate the model creation and update of the required input information?

RQ2 is answered in the following section through the study case at VCT where a gap analysis over the input data in VCT is presented. *Figure **15*** provides an overview of relevant sources for data and information needed in order to create a DES model. The gap analysis is presented according to the theory-introduced category A, B and C data, divided in station- and resource level, and transportation. These in turn, were presented under the subheads introduced in *Figure **15*** input data sources; support information and program software.

6.1 Category A Data: Available

Data and information presented in this section is classified as available and collectable. The quality are however questionable for some of the parameters. *Table 6* provides a summary of the A data based on parameter and related information are divided into four columns with source, a short explanatory description, when the data is logged, and preferred update interval for the StreaMod project. The update interval is defined in order to obtain an approximate number of 250 samples of the same kind of data, depending on the occurrence of a registry a different interval is needed.

Table 6 Gap analysis category A data

Gap Analysis				
Category A data: available				
Station- and Resource Level				
Parameter	Source	Description	Logged	Update
Cycle Time	CTview	From start-to-start. 35 days detailed info	Real time automatic.	2 weeks
	TATS script	From robot start to last robot end 45 days basic info	Real time automatic.	2 weeks
Processing Time	CTview	From robot start to last robot end Not accurate!	Real time automatic.	2 weeks
Disturbance	SUSA	Start of failure related: P, K, T or U 1 year of historical data	Monitor change every 25 seconds due to old PLC.	Monthly
- Personnel (P)	SUSA	When maintenance personnel open the station door. Comments in SUSA for more precise problem definition.	Every 25 seconds due to old PLC.	Monthly

- Quality (K)	SUSA	When PLC detects a quality error	Every 25 seconds due to old PLC.	Monthly
- Technical (T)	SUSA	Robotic failure, maintenance failure etc.	Every 25 seconds due to old PLC.	Monthly
- Maintenance (U)	SUSA	Scheduled maintenance of e.g. robots	Every 25 seconds due to old PLC.	Monthly
Product Mix	CTview / TATS	Related to cycle time and processing time	Real time automatic.	2 weeks
	SUSA	Related to disturbances	Every 25 seconds due to old PLC.	2 weeks
	TAP	Deciding on sequence order	Real time automatic	2weeks
Transport	CTview	From end of processing to start of processing. Definition unclear. Observations showed a different time than the time stamp.	Real time automatic.	2 weeks
Layout	TATS	Overview with line name and station number. Only bottom floor available.	Static.	Every 3-6 months
	Auto CAD	Detailed view with line name and station number.	Last update ?	Every 3-6 months
Process Flow	TATS	Real time color coded connected to body type	Real time automatic.	With process changes
	Driftsanvisning	Description over the station logic and resources.	By body type release. Last update 2012.	With process changes
	TAP - systembeordring	Document describing inner and outer side ordering and roof. (Line-51/52/56/57 and /54)	Static. Last update 2007.	Static
	Process Designer	PERT and Operation tree	By body type release	Every 3-6 months
Resources	PD	All objects in a station and material input (consumption)	Weekly/Monthly.	Weekly/Monthly

Transport

Parameter	Source	Description	Logged	Update
Product Mix	TAP	Sides to 11-54-020.	Real time automatic.	Every 2nd week
	TATS	Percentage mix under the head line *TA1 Palett Mix*	Static.	Every month

Layout	Auto CAD	Upper floor OEMs.	Static.	With process changes
Process Flow	Auto CAD	Arrows in upper floor drawings.	Static.	With process changes
Resources	TATS	Number of outer-side fixtures. Needs update.	Static.	Every 2nd month

The update interval should be viewed as a way to assure the quality of the data collected since it might have inaccuracies normally due to changes in production lines or products.

6.1.1 Input Data Sources

In the TA factory (body shop) at VCT there are several input data sources that contain relevant data and/or information for the creation of a DES model.

- CTview
- TAP
- SUSA
- TATS Script

This data is generated and stored through a SCADA system called “Virtual Device” (VD) which registers the different PLC signals timestamps sent from the shop floor processes. TATS Script and SUSA are the two main data sources used in the thesis to extract information

Both CTview and TATS Script provide the data for processing and transportation time connected to each station. A limitation with CTview, as a data source, is the short storage time because the query for historical data can be a maximum of 35 days. Thus there is a limitation in the storage time.

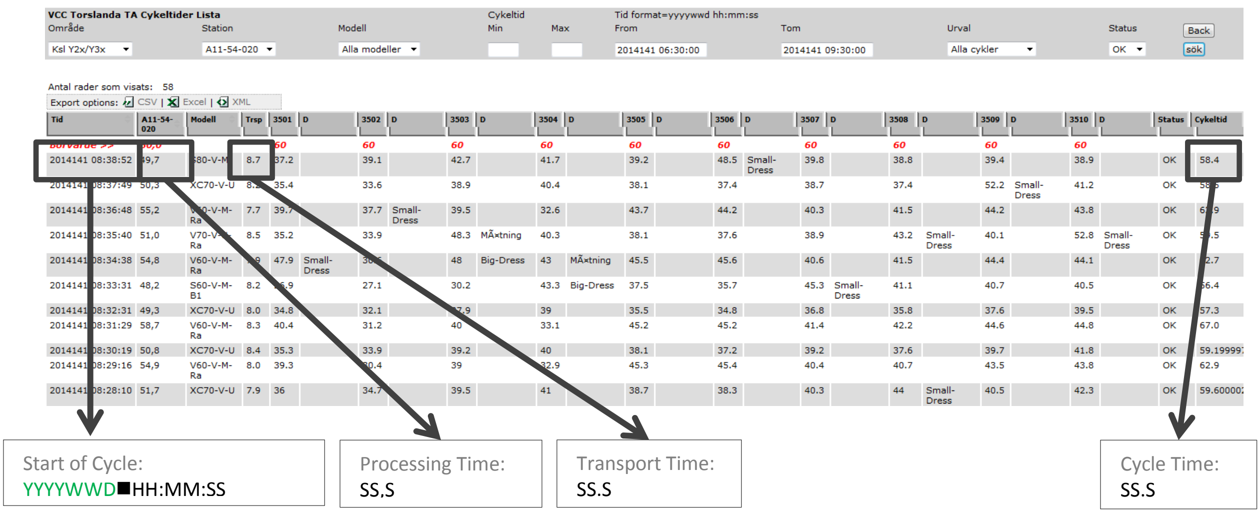


Figure 20 CTview

However, by using TATS an MS Excel download can be reached which can provide additional data over a total of 45 days. The TATS option requires a manual change of station number directly in the webpage name in order to find and output data for the desired station. Another limitation with the

TATS option is the missing robot specific processing time, which can be found in CTview between Transport- and Cycle Time, see *Figure 20.*

SUSA is, as explained in section 5.1.3, the data source for disturbances connected to each station. At resource level it is possible to find failure cause to some extent related to the classification explained below. By typing in the station name, e.g. 11-54-020 (the framing station), the following information of interest for DES application can be obtained.

- Disturbance classification: FS (Blocking), VS (Starvation), T (Technical failure), P (Personnel related failure), U (Maintenance), and K (Quality related failures)
- Disturbance Start
- Disturbance Stop (Not accurate)
- Loss
- Product Mix (V60,V70,S60,S80)

Technical failures can be traced to the object causing the alarm but is not exactly defined. *Figure 21* shows an example of how SUSA looks and in what format the information can be found.

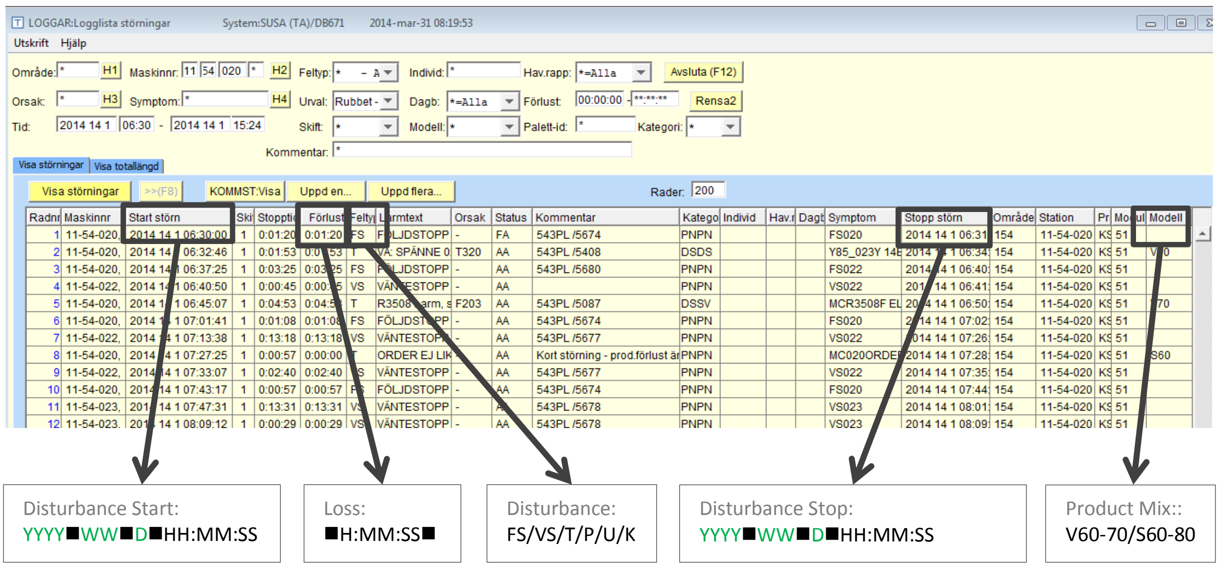


Figure 21 SUSA

The start of disturbance timestamp has proven to be close to accurate, but the stop timestamp is not. This fact is presented further in section 6.2 under category B data.

TAP is the ordering system in VCT and sets the body type sequence. As can be seen in *Figure 22* the system has a Swedish operating language. Since TAP logs the Escort Memory (EM)-card at every station it also provides more information usable for simulation purpose. Ordering point of complete sides, inner sides, roof and body type can be found. There is also the possibility to see real time buffer sizes between Lines.

The lower picture in *Figure 23* shows an example from the BEO option with ordering of complete-left-side (SIDVK), complete-right-side (SIDHK), and roof (TAK) combined with palette ID-number, e.g. “51-9-79/3”. For the sides, the first two numbers, 51, indicates which Line-buffer the palette is ordered from. This is not true for the roof. The body type characteristic (Egenskaper) can be read in the column farthest to the right (see Karosstyper A – B Fabrik for body type identification table).

Note how the naming here is slightly different from SUSA and CTview. In SUSA the station naming is standardized to “11-54-020” and in CTview stations use the prefix "A", e.g. "A11-54-020". In TAP it is “1154020” without the “-“. It can be thought of as a small thing but when retrieving the data from the systems this creates issues because the retrieving process cannot be replicated.

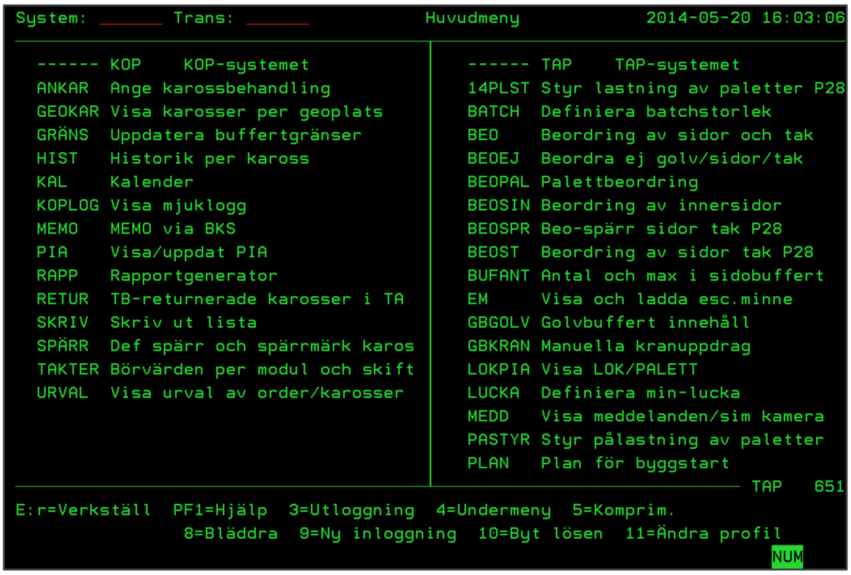


Figure 22 TAP introduction page overview

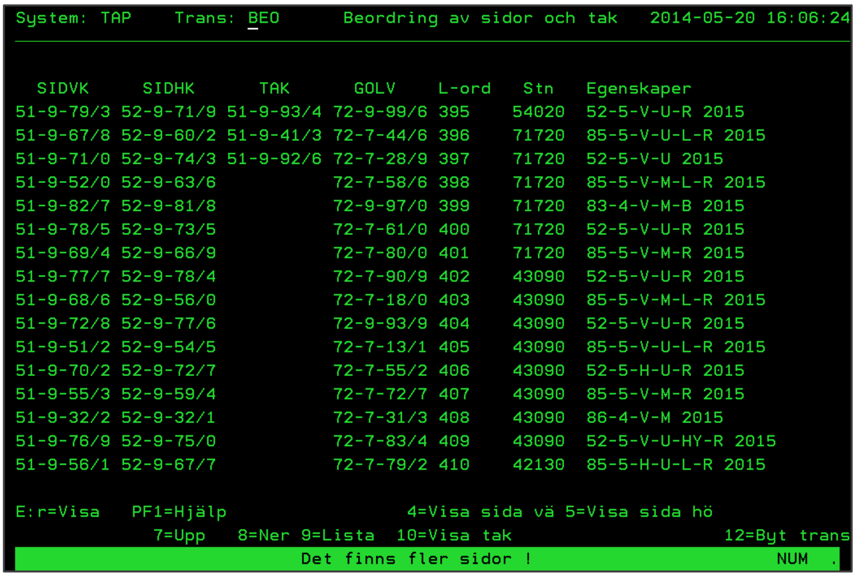


Figure 23 BEO option overview in TAP

6.1.2 Program Software Sources

Some information available for the simulation user that is stored in Process Designer, is the eBOP that can be displayed in the form of a PERT diagram (Program Evaluation and Review Technique), see *Figure 24.* In the PERT diagram the sequence of the operations is displayed along with the material flow. The diagram also displays the part sources and where parts are consumed. It also can display the resources used on each station when they are related to the process and the allocated time for the operations.

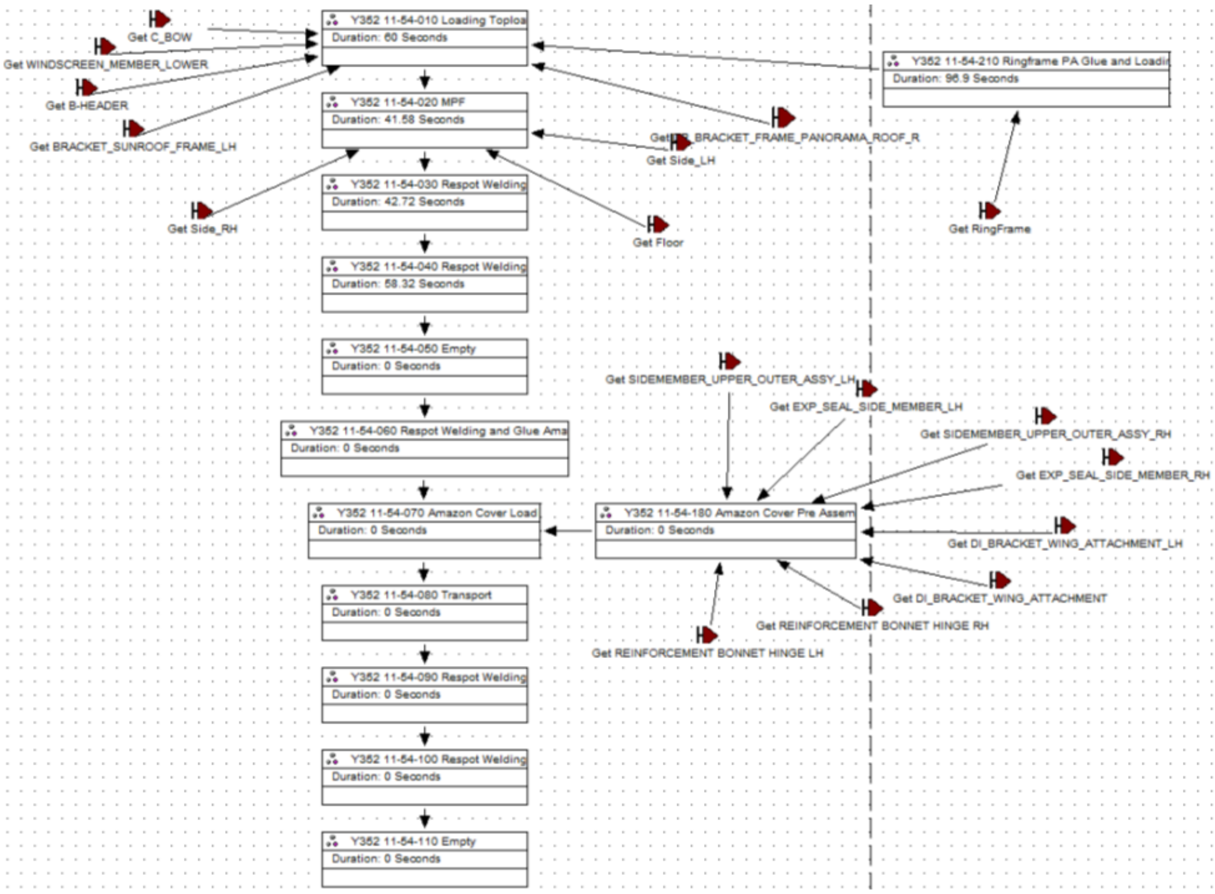


Figure 24 PERT diagram from Process Designer

Other available structure loaded in Process Designer by line builders, according to Volvo specification document is the resource tree (see *Figure 25*). The simulation modeler can view the components that compose the stations, lines and areas of the factory. If the availability parameters of the components are known then they can be used to set up the proper availability in the resources of the simulation.

Object	Positioning	Comment
VCG	Factory zero	No positioning
GA	T=[0,0,0,0,0,0]	No positioning
BODY	T=[0,0,0,0,0,0]	No positioning
'GA1 38600' - 'BSO LH'	T=[0,0,0,0,0,0]	No positioning
'GA2 30000' - 'PA_SIDES'	T=[0,0,0,0,0,0]	No positioning
'GA2 31000' - 'BSC LH'	T=[0,0,0,0,0,0]	No positioning
st31020	Tstation	Station position relative to Factory zero
Robots and tools	T=[0,0,0,0,0,0]	No positioning
r31020_01	T=[0,0,0,0,0,0]	No positioning
r31020_01	Tobject	Object position relative to Tstation
r31020_01_01	Tobject	Object position relative to Tstation
gh31020_01c	Tobject	Object position relative to Tstation
gh31020_01d	Tobject	Object position relative to Tstation
ft31020_01_01cd	Tobject	Object position relative to Tstation
Transport fixing	T=[0,0,0,0,0,0]	No positioning
Fixtures	T=[0,0,0,0,0,0]	No positioning
fm31020_01_01d	Tobject	Object position relative to Tstation
fm31020_01_01c	Tobject	Object position relative to Tstation
fd31040_03	Tobject	Object position relative to Tstation
Conveyors	T=[0,0,0,0,0,0]	No positioning
ca31020_01c	Tobject	Object position relative to Tstation
ca31020_01d	Tobject	Object position relative to Tstation
3D layout	T=[0,0,0,0,0,0]	No positioning
Misc	T=[0,0,0,0,0,0]	No positioning
fd31020_01	Tobject	Object position relative to Tstation
fd31020_70	Tobject	Object position relative to Tstation
Geo31020	T=[0,0,0,0,0,0]	No positioning
cable_channels31020*	Tobject	Object position relative to Tstation
fences31020*	Tobject	Object position relative to Tstation
fume_extractors31020*	Tobject	Object position relative to Tstation

Figure 25 Resource tree and hierarchy

6.1.3 Support Information

All data and information cannot be directly found in the input data sources or program software sources. Due to this shortage additional support information has been investigated as potential alternative source options. The following document and program introduction are the result of this investigation and is found to contain relevant information for the purpose of future automatic generation of DES models.

- Driftsanvisning (operation instructions)
- Mitsubishi PLC
- Auto CAD Layout
- TAP Systemdokumentation (TAP system documentation)

The Driftsanvisning manuals contain information about the logic for each station in an entire line related to each body type. However, the body types are expressed in terms of Y286 instead of S80 etc. just as in TAP (see Karosstyper A – B Fabrik for the detailed body type labeling and description, not included in thesis). It is useful for the understanding of the process in connection to walking the line and building a simulation model. The document is also updated since the introduction of the latest car model, the S60.

All steering of lines are done through the Mitsubishi PLC. Initially it was intended to look through the PLC to gain understanding of how the steering is programmed. Because the PLC is of an outdated version this became very difficult. It is programmed for each station according to the Mitsubishi program structure. There are few comments which are written with a lack of standardization, and thereby attempts to follow the code are difficult - unless the user has previous experience in the software.

Auto CAD was found useful to get a visual overview of both top and bottom floor. *Figure 26* is an example of a drawing with overview of the thesis delimited area, line-51/52/54/56/57.

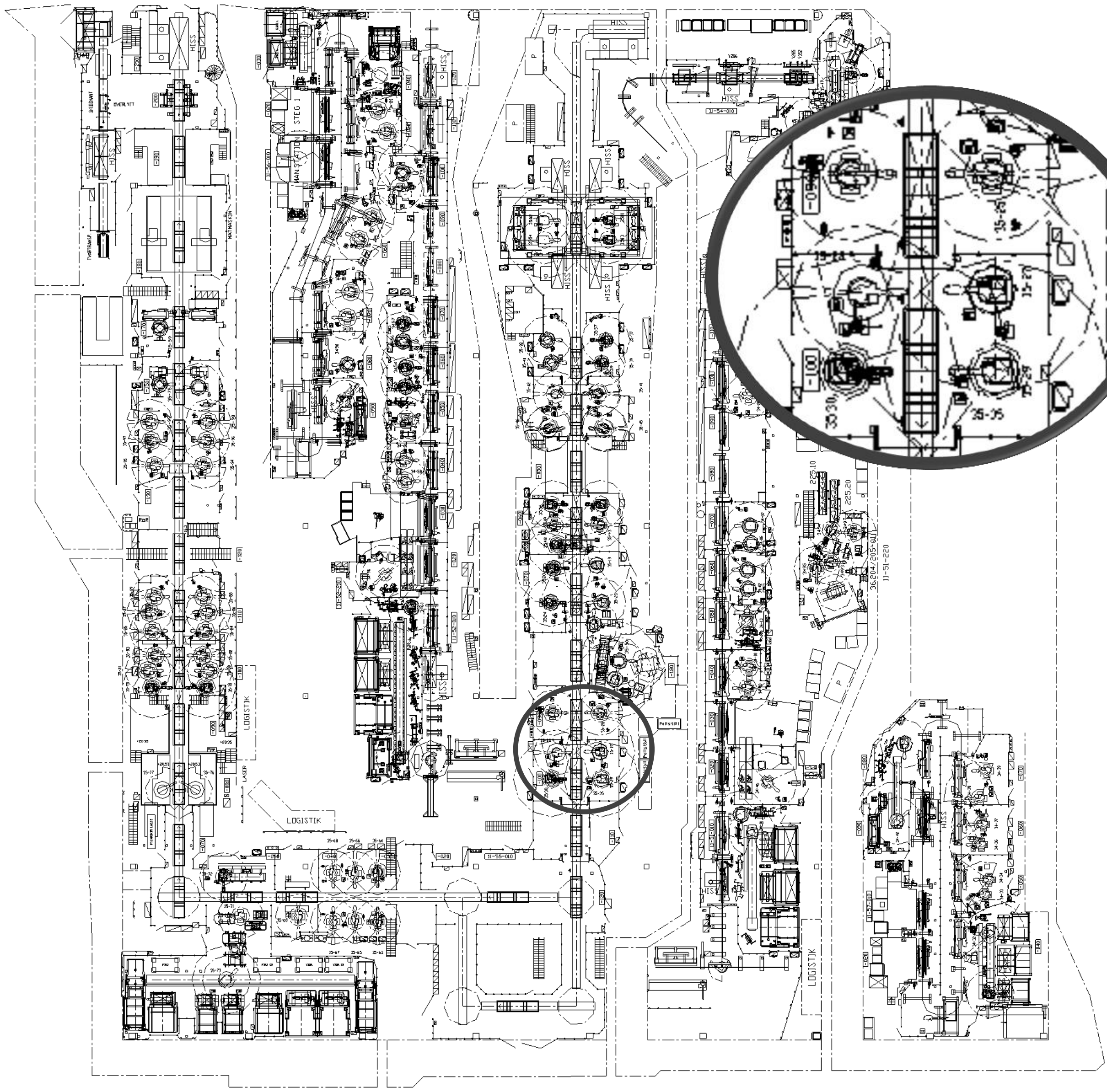


Figure 26 Auto CAD drawing over delimited production body shop area in VCT

Robots are surrounded by circles and are easy to see when zooming into the drawing. On the side of each station the station name can be read e.g. "– 100". This can be seen in the right circle in the drawing, which shows an enlarged section. The individual robot number can also be read and information as displayed here "pallställ" ("pallet rack" in English). The squares indicate body position.

TAP beordring describes the logic behind steering and ordering of roof, BSI and BSO. It is very clear and gives precise description. By reading this document the understanding of how TAP works becomes clearer as it is a type of description manual to TAP.

6.2 Category B Data: Available But Not Collectable

Data and information in this section are available but has not been gathered due to limited accessibility or the need of complicated procedures involved in the gathering process. All fields filled in with orange in *Table 7* of this section are connected to category B data.

Table 7 Gap analysis category B data

Gap Analysis				
Category B data: Available But Not Collectable				
Station- and Resource Level				
Parameter	Source	Description	Logged	Update
Availability	Supplying Line-builder	Info can be reached if requested. Not standardized available in VCT.	No.	
Disturbance	SUSA	Failure related: P, K, T or U Logged but with low quality.	Every 25 seconds due to old PLC.	
Cycle time → disturbance	CTview or SUSA	Can be combined by using timestamps.	No.	
Processing time → disturbance	CTview or SUSA	Can be combined by using timestamps.	No.	
Transport → disturbance	CTview or SUSA	Can be combined by using timestamps.	No.	
Disturbance → cause	SUSA	Not sufficient documentation on causes. Operators do not add info standardized.	At failure.	
Transport				
Parameter	Source	Description	Logged	Update
Product Mix	TAP		Real time automatic.	
	TATS	Shows static figures which are not updated regularly of fixtures for outer and inner sides. (Line-51/52/56/57)	Static.	
Layout	Auto CAD	Different versions available.	Static. Needs update.	

6.2.1 Input Data Sources

The disturbance data is logged and stored in SUSA at a continuous basis. However, the disturbance data has insufficient quality. The actual disturbance duration time cannot be identified as the alarms continue to send throughout the processing time. That is from start of disturbance until the entry of a new product. Thus even if the failure has been corrected the disturbance alarm will continue. This was realized during time studies of videos where the alarm times in SUSA for a specific body was matched with the video times.

In the current input data sources used at station level there is no interconnection between CTview and SUSA. Processing time and cycle time are not displayed connected to disturbances. Since the cycle time is affected by disturbances it is necessary to connect the two parameters, in order to reach a good input data quality for the simulation model. This can be done with the help of the time stamps. With the creation of a macro in MS Excel™ the connection has been accomplished through a cleaning process. All cycle times affected with disturbances have been removed in order to find the correct processing time.

At resource level the situation is the same with no interconnection between CTview and SUSA. The data quality is questioned and considered insufficient at station level and is not trustworthy at resource level. Hence if data at resource level is desired a process on gathering the data needs to be assigned. At the moment the data should be available at in-house virtual simulators of PD. As mentioned in the previous section there is a cause classification connected to SUSA. It is possible to find T-failures and alarms triggered by a specific robot. Maintenance personnel also fill in the comments when opening the door to a station, which triggers a P alarm. The yellow marking is due to lack of data here and the quality. Standardization in the comment writing is limited and the operator shows a lack of motivation to write comments due to insufficient background knowledge and understanding.

6.2.2 Program Software Sources

Even if the processes can be displayed in PERT diagrams as mentioned in section 6.1.2, no process times or other simulation attributes are fed. Also it can be seen that no transport systems are considered as part of the process. It can be seen from *Figure 27* that certain attributes, with importance for DES, could be added to the process objects and thereby be passed forward to the Simulation software. Even if these attributes are designed out-of-the-box in the software, there is no requirement in "VCC Manufacturing Simulation Specification" for the suppliers to feed them.

Regarding resources, in best-case scenarios, the supplier can make good estimates on the performance of the equipment based on similar resources already installed in other places. It has been detected through non-structured interviews that percentage availability provided by the equipment supplier is the most used parameter to describe the performance of resources when building a simulation model. Nevertheless, these parameters are not fed into the software. Also different resources and operations names are logged in different ways into the different systems as discussed on Chapter 8 Discussion & Suggestions.

In Process Designer™ there is also no information about the availability or real performance of the resources. Depending on what kind of object is selected in Process Designer™, different attributes can be filled out. *Figure 27* shows the simulation attributes that can be setup inside the instances of Resources used in the stations. These attributes are related to resource characteristics that can be further used when the simulation model is constructed.

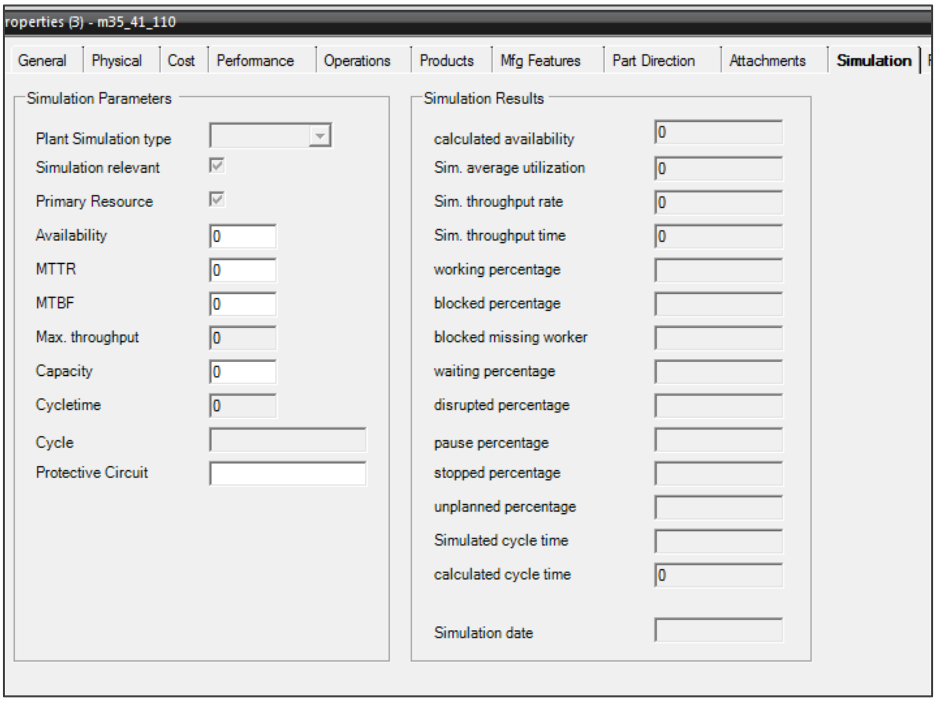


Figure 27 Simulation attributes, which can be setup in instances of Resources in Process Designer™

The attributes for Simulation purposes change depending on the type of object inside Process Designer, *Figure 28* shows the attributes that can be setup in Process Objects. Furthermore *Figure 29 Simulation attributes found in the Product Object class in Process Designer*, shows the attributes that a Product object class has available to the user to fill in.

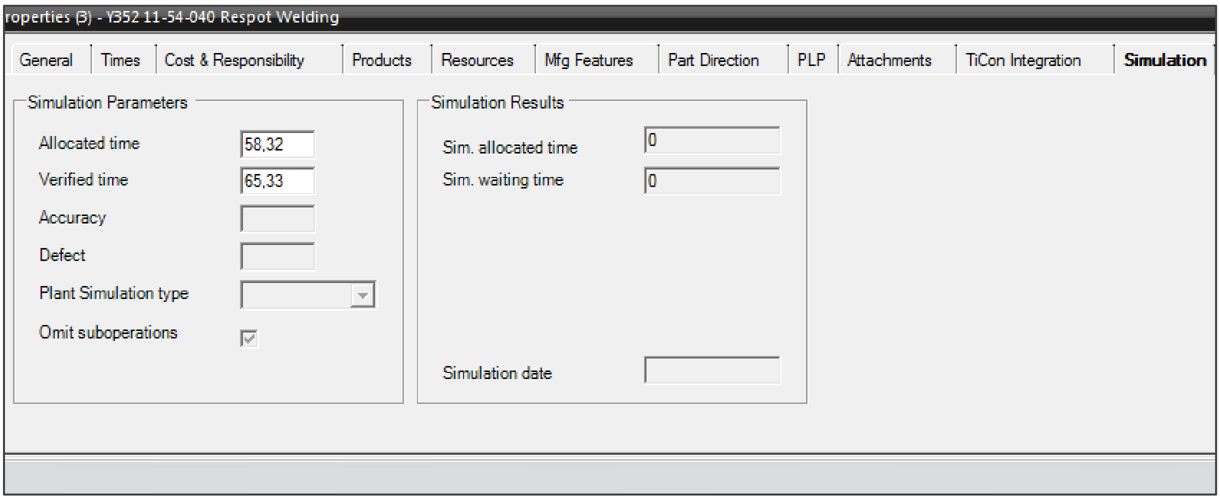


Figure 28 Simulation attributes which can be setup in Process Objects in Process Designer™

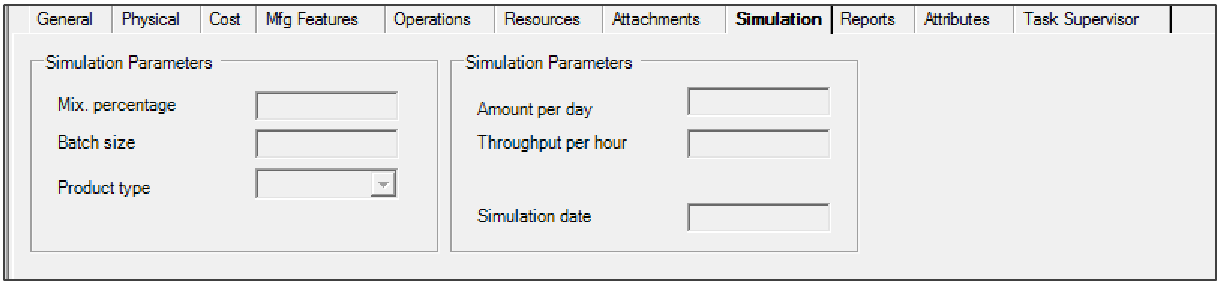


Figure 29 Simulation attributes found in the Product Object class in Process Designer™

It becomes relevant for RQ2 if these simulation attributes are stored in the software so that a Script can extract them and use them to create and update simulation model automatically.

6.2.3 Support Information

When it comes to availability it is the line-builders and resource distributors who hold the information. It can be accessed by asking suppliers, but the information cannot be found in the investigated systems.

6.2.4 Transport

The logic behind the steering of the transportation systems, for the side lines, line-51/52/56/56, are not directly accessible but can be found by combining different sources: the ordering sequence can be viewed in TAP under BEO; the buffer location and format can be found in Auto CAD; but the transportation time needs to be calculated, as there are no direct data in CTview for transportation in between of Lines.

6.3 Category C Data: Not Available

The last section concerns category C data and is marked by read in *Table 8*. It is data which is not available at all at VCT and should be added to the input data systems.

Table 8 Gap analysis category C data

Gap Analysis				
Category C data: Not Available				
Station- and Resource Level				
Parameter	Source	Description	Logged	Update
Disturbance → cause	SUSA	Not sufficient information on what causes the failure on resource level.	No.	
Transport				
Parameter	Source	Description	Logged	Update
Time	TAP	If extensive calculations are done it can be found. But should be more easily accesable.	No.	
Buffer	-	Operator knowledge and go-see-yourself needed to find info.	No.	At rebuilding

Layout	Auto CAD	Latest version with S60 not available. No info on dedicated rails.	Static.	
Resources	PD	Not available. (OEMs and hangers)	No.	

6.3.1 Input Data Sources

At station level there is no category C data found or viewed as interesting when building the simulation model at VCT. The only category C data found is at resource level and concerns disturbance cause classification. Currently the systems do not link disturbance alarms more than in the previously presented classifications T, U, P and K (starvation and blocking are not directly contributors to stop alarms). There is for instance not always possible to identify which robot causes an alarm and the actual cause, e.g. gripper, maintenance etc. To clarify, U is only scheduled maintenance and not failures caused by neglected maintenance which instead sets off a T-alarm. An important finding here is the knowledge in how the alarms function. The PLC can only send one alarm at once and it is the most crucial alarm, which triggers a signal. This means that only one alarm is sent to SUSA even if several failures occur at the same time.

6.3.2 Program Software Sources

VCT does currently not utilize PD for the purpose of DES. No further data than out-of-the-box parameters are required to be collected directly from these sources.

6.3.3 Support Information

Neither of the support information sources is found severely lacking either.

6.3.4 Transport

No information is available concerning amount of buffer places and size nor is there any updated layout available for the OEMs in the VCT systems. To build the simulation model in the thesis, it was necessary to have this information. By walking the lines and talking with operators, the information was gathered and the results displayed in the figures below. *Figure 30* shows an overview of the buffer places found. As the buffer places were counted at sight there is an error possibility. However, found results can be used as a foundation when updating the Auto CAD layout.

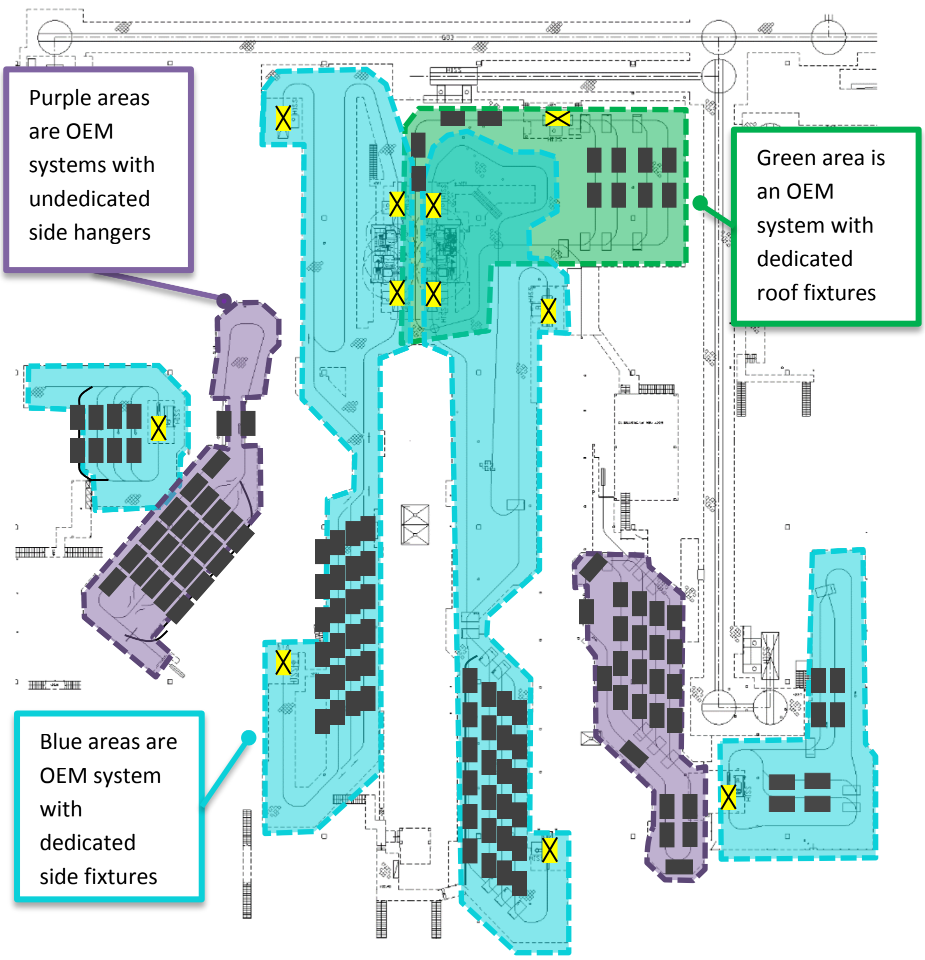


Figure 30 Gathered data related to buffer places in the EOM transportation system

The lack of update can be notice between *Figure 31* and *Figure 32*. *Figure 31* shows an older version with color markings over areas which are different compared to the newer version displayed in *Figure 32*. *Figure 32* in turn shows dedicated tracks in the EOM roof-system. It also provides a visual understanding of currently not updated areas in the Auto CAD, clearly related to the latest manufacturing addition of body type S60, which are indicated with blue.

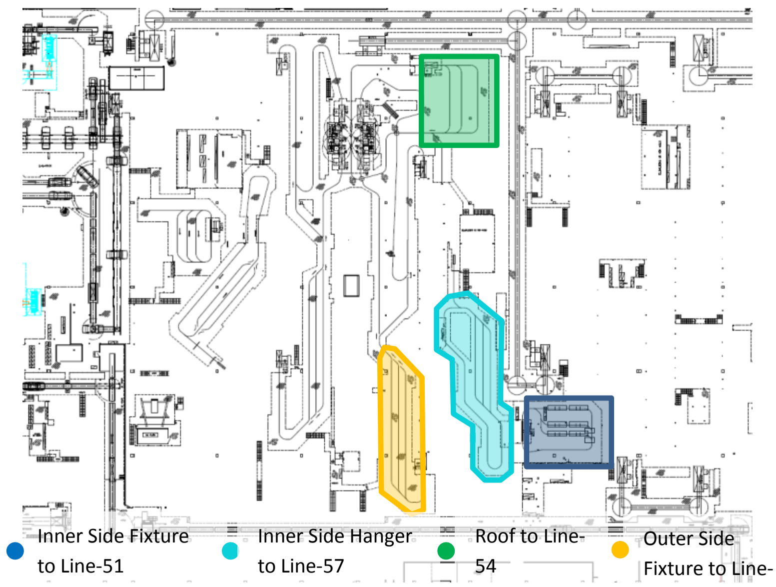


Figure 31 Not updated Auto CAD drawing

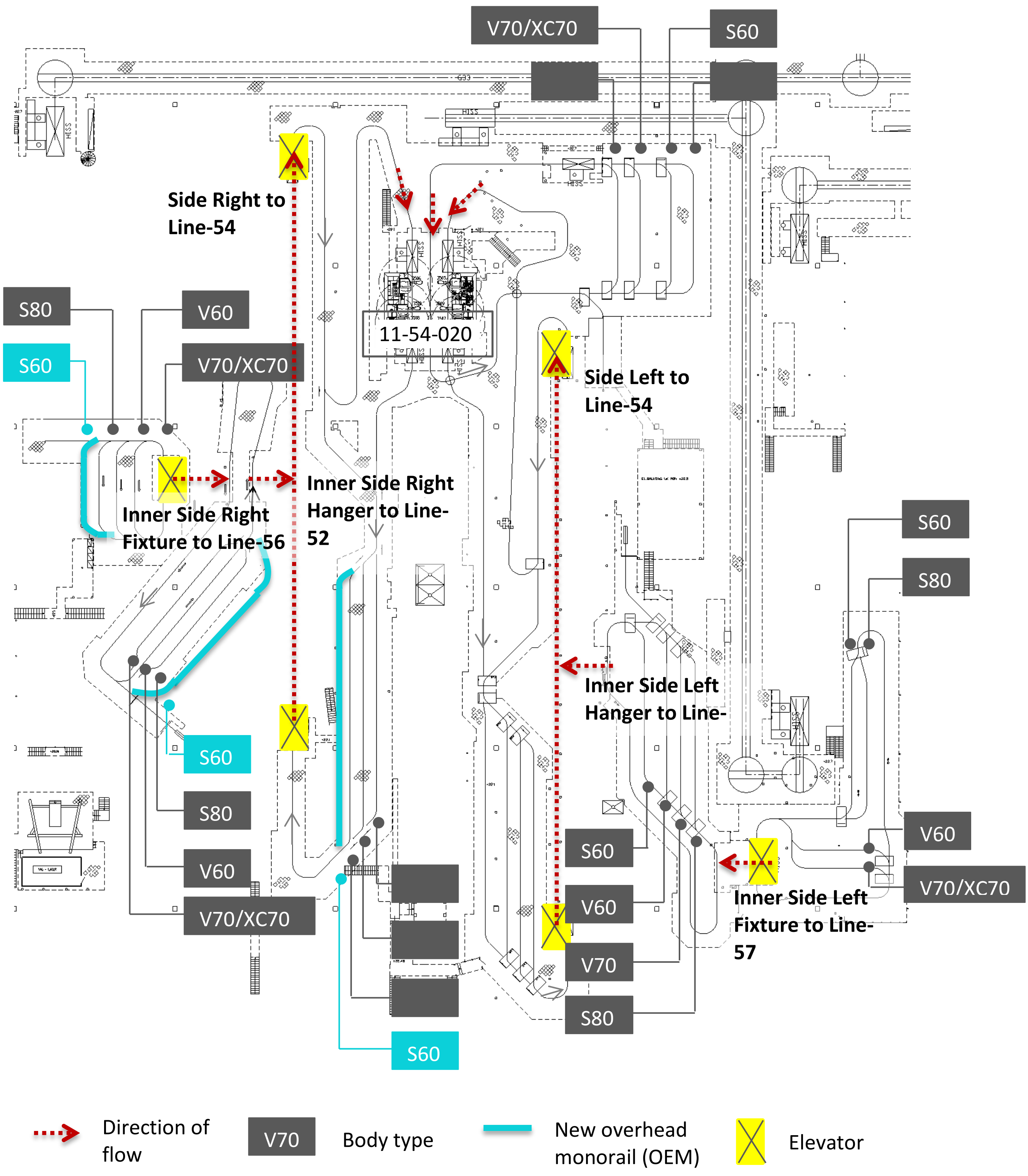


Figure 32 Auto CAD drawing with dedicated transport tracks and added not updated areas

7 Input Data Management at VCT

This chapter provides results based on the theory in section 2.2, Input data management, and goes through the three headlines in the methodology process: Data collection, Data processing, and Interfacing. The investigated data sources are CTview and SUSA. The first step described relates to how the project utilized the manual data collection method according to Methodology A, see section Data input methodologies. The second step was the processing which was made in MS Excel™ with two tailored macros, programmed to fit SUSA and CTview. This enabled automatic processing. The third step, interfacing, will be mentioned more briefly as it resulted to be out of the thesis limitations.

7.1 Overview of the available formats

What is interesting to notice is the lack of standardized format in use of date/time and station number. This creates issues in the data processing step as the programming needs to be individually customized. An overview of the time formats in the used systems can be seen in *Table 9*.

Table 9 Overview of the data format in the information sources at VCT

	Processing time	**Transport time**	**Cycle time**	**Delta/ (Start to start)**	**Product Mix**	**Down times**
Origin	CTView / TATS	CTView	CTView	TATS	CTView / TATS	SUSA
Format	SS,XX (number)	SS.XX (text)	SS.XX (text)	SS (number)/ YYYY-MM-DD HH:MM:SS	V60-V/H-M/U-Var (Text)	H:MM:SS
Processing	Compare and filter with upper time limit (90sec).	Substitute ”.” for ”,” and use VALUE formula to change to number format	Substitute ”.” for ”,” and use VALUE formula to change to number format	Filter with upper time limit and those which contain a failure. Used in simulation model.	Group variants per car type and filter database using DMAX, DMIN, DAVERAGE, DSTDEV functions	Trim spaces, format to time, Change to seconds by multiplying by hour, minute, and seconds
Extracted	Per product, and per Robot, filtered with upper limit	Inconsistent with observations	Processing + Transport Missing outbound transport time and disturbances	Clean cycles per product type	Maximum, Minimum, Mean, Std. Deviation per product type	Duration and interval in seconds [s]
Updated	2 weeks (>~250 filtered samples)	2 weeks (>~250 filtered samples)	2 weeks (>~250 filtered samples)	2 weeks (>~250 filtered samples)	Every variant introduction or 3-6 months.	~1 year data to have ~250 samples

7.2 CTview

This section presents findings of the CTview system at VCT divided into three steps: collection, processing and interfacing; as established in section 2.2.

7.2.1 Data Collection

Data regarding processing times could be collected either through CTView or using TATS Script tool. For the purpose and time range decided for this study case, the TATS Script was used to collect station cycle time data. A folder was created using the station identifier (e.g...//11-54-020/) for each station. The MS Excel™ generated by the TATS Script was then saved inside the station folder using the same station identifier and the prefix “CT” (e.g. CT1154202.xlsx).

Another file with the station identifier and the prefix “SUSA” was saved for each station of lines 54, 51 and 52 (e.g. SUSA1154020.xlsx). In these files, all kinds of disturbances registered in SUSA for the same time period were stored.

7.2.2 Data Processing

A MS Excel™ file containing a Macro was developed in order to process the collected data for every station. The Macro was programmed to extract delta times (start-to-start) from the previously downloaded files and filter the data as mentioned previously on chapter2.2.3. This also contains a Macro to allocate the failures and delete those cycles that contain a disturbance as explained in section 4.3 and an additional one to filter out the cycles out of regular shifts hours. The result is a table (e.g. *Figure 33*) containing the proposed cycle times (processing + transport times) for each product type in each station. This times table can be easily copy-pasted into the simulation model stations.

Filtered Cycle times				
Upper Time Limit for Processing Times			[seconds]	90,00
	MIN	MAX	AVERAGE	STDDEV
S60	49,00	90,00	61,44	5,20
S80	49,00	88,00	61,20	5,16
V60	13,00	90,00	61,94	5,40
V70	14,00	90,00	60,05	6,20
XC70	43,00	88,00	60,09	6,30
V70/XC70	14,00	90,00	60,07	6,26

Figure 33 Cycle times after processing data.

7.2.3 Interfacing

No interfacing between applications was programmed but the use of a standardized spreadsheet for all the stations allows the creation of an interfacing script in an easier way if further investigated.

7.3 SUSA

This section presents findings of the SUSA system at VCT divided into three steps: collection, processing and interfacing; as established in section 2.2.

7.3.1 Data Collection

The data collection process was performed manually. Disturbance data was gathered, in a folder named based on line and station number, from week 1 to week 14 of 2014. This had to be done manually as the data could not be downloaded in an MS Excel or other file format. An example of the data gathered for station 11-51-010 can be seen in *Figure 34*. Each individual MS Excel™ workbook was name according to the station name, e.g. S11_51_010. In all files the same headline as used in SUSA was added with the information of what the columns contains, for instance "Radnr", "Maskinnr", "Start störn", etc.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Radnr	Maskinnr	Start störn	Skift	Stopptid	Förlust	Feltyp	Larmtext	Orsak	Status	Komment	Kategori	Individ	Hav.rapp	Dagbok	Symptom	Stopp stö	Område	Station	Prodpkt	Modul	Modell
2	1	11-51-010	2014 02 2 06:48:53	1	0:01:22	0:01:22	T	CYKELTIDSFEL		AA		PNPN				MC010CYI	2014 02 2	151	11-51-010	KSL	51	V60
3	2	11-51-010	2014 02 2 08:18:08	1	0:01:23	0:01:23	P	GRIND STN.010		AA	511PL /50	PNPN				MC010F7	2014 02 2	151	11-51-010	KSL	51	S60
4	3	11-51-010	2014 02 2 09:08:13	1	0:05:33	0:05:33	T	CYKELTIDSFEL		AA	Symptom	PNPN				MC010CYI	2014 02 2	151	11-51-010	KSL	51	S60
5	4	11-51-010	2014 02 2 12:37:52	1	0:14:10	0:14:10	T	TRANSPORT STC		AA	Symptom	PNPN				MC010F7I	2014 02 2	151	11-51-010	KSL	51	V70
6	5	11-51-010	2014 02 3 07:04:26	1	0:02:25	0:02:25	T	R3401 Larm, se	H300	AA	Spänne e	DSDS				MCR3401	2014 02 3	151	11-51-010	KSL	51	S60
7	6	11-51-010	2014 02 3 07:40:17	1	0:02:17	0:02:17	L	CYKELTIDSFEL	Ö200	AA	511PL /56	PLAN				MC010CYI	2014 02 3	151	11-51-010	KSL	51	S60
8	7	11-51-010	2014 02 3 21:22:59	2	0:02:45	0:02:45	P	GRIND STN.010	P202	AA	Felladdn	PNLK				MC010F7	2014 02 3	151	11-51-010	KSL	51	S60
9	8	11-51-010	2014 02 4 07:14:01	1	0:05:02	0:05:02	T	CYKELTIDSFEL	T321	AA	Symptom	DSDS				MC010CYI	2014 02 4	151	11-51-010	KSL	51	V70
10	9	11-51-010	2014 03 1 08:02:33	1	0:01:22	0:01:22	P	TRANSPORT STC	P200	AA	Processt	PNLK				MC010F7I	2014 03 1	151	11-51-010	KSL	51	V70
11	10	11-51-010	2014 03 1 18:28:01	2	0:06:24	0:06:24	T	CYKELTIDSFEL	T320	AA	Symptom	DSDS				MC010CYI	2014 03 1	151	11-51-010	KSL	51	V70
12	11	11-51-010	2014 03 1 19:05:32	2	0:02:45	0:02:45	T	CYKELTIDSFEL	T320	AA	Signalfel	DSDS				MC010CYI	2014 03 1	151	11-51-010	KSL	51	V70
13	12	11-51-010	2014 03 1 20:27:11	2	0:08:13	0:08:13	T	VÄ: SPÄNNE 010	T320	AA	Symptom	DSDS				Y85_010Y	2014 03 1	151	11-51-010	KSL	51	V70
14	13	11-51-010	2014 03 1 20:37:41	2	0:04:34	0:04:34	L	GRIND STN.010	Ö200	AA	511PL /50	PLAN				MC010F7	2014 03 1	151	11-51-010	KSL	51	V70
15	14	11-51-010	2014 03 1 21:41:03	2	0:01:22	0:01:22	T	VÄ: SPÄNNE 010	T320	AA	Signalfel	DSDS				Y85_010Y	2014 03 1	151	11-51-010	KSL	51	V70
16	15	11-51-010	2014 03 1 21:42:53	2	0:04:06	0:04:06	T	GRIND STN.010	T320	AA	Signalfel	DSDS				MC010F7	2014 03 1	151	11-51-010	KSL	51	V70
17	16	11-51-010	2014 03 1 23:30:37	2	0:01:49	0:01:49	T	R3401 Larm, se	H300	AA	Detaljgiv	DSDS				MCR3401	2014 03 1	151	11-51-010	KSL	51	V60
18	17	11-51-010	2014 03 2 08:14:23	1	0:01:50	0:01:50	T	CYKELTIDSFEL	T320	AA	Signalfel	DSDS				MC010CYI	2014 03 2	151	11-51-010	KSL	51	V70
19	18	11-51-010	2014 03 2 12:18:14	1	0:03:11	0:03:11	T	VÄ: SPÄNNE 010	T321	AA	Slagg på	DSDS				Y85_010Y	2014 03 2	151	11-51-010	KSL	51	V70
20	19	11-51-010	2014 03 2 12:21:53	1	0:01:22	0:01:22	T	GRIND STN.010	T321	AA	Slagg på	DSDS				MC010F7	2014 03 2	151	11-51-010	KSL	51	V70
21	20	11-51-010	2014 03 2 12:39:35	1	0:02:17	0:02:17	T	VÄ: SPÄNNE 010	T320	AA	Signalfel	DSDS				Y52_010N	2014 03 2	151	11-51-010	KSL	51	V60
22	21	11-51-010	2014 03 2 14:46:08	1	0:00:28	0:00:28	P	GRIND STN.010	-	AA	511PL /50	PNPN				MC010F7	2014 03 2	151	11-51-010	KSL	51	S80
23	22	11-51-010	2014 03 2 14:47:03	1	0:00:55	0:00:55	P	GRIND STN.010	-	AA	511PL /50	PNPN				MC010F7	2014 03 2	151	11-51-010	KSL	51	S80
24	23	11-51-010	2014 03 3 09:33:41	1	0:08:13	0:08:13	T	R3401 Larm, se	H200	AA	Sida låg	DSDS				MCR3401	2014 03 3	151	11-51-010	KSL	51	V70
25	24	11-51-010	2014 03 3 09:58:41	1	0:01:39	0:01:39	K	GRIND STN.010	K100	AA	Givare på	DSGT				MC010F7	2014 03 3	151	11-51-010	KSL	51	V60
26	25	11-51-010	2014 03 3 10:42:17	1	0:04:29	0:04:29	K	GRIND STN.010	K100	AA	Givare på	DSGT				MC010F7	2014 03 3	151	11-51-010	KSL	51	V60
27	26	11-51-010	2014 03 3 12:17:19	1	0:08:48	0:08:48	T	R3401 Larm, se	E108	AA	Justering	DSDS				MCR3401	2014 03 3	151	11-51-010	KSL	51	S80
28	27	11-51-010	2014 03 3 12:56:38	1	0:02:42	0:02:42	T	R3401 Larm, se	E108	AA	Givare ej	DSDS				MCR3401	2014 03 3	151	11-51-010	KSL	51	S80
29	28	11-51-010	2014 03 3 14:27:01	1	0:00:53	0:00:53	P	GRIND STN.010	-	AA	511PL /50	PNPN				MC010F7	2014 03 3	151	11-51-010	KSL	51	V60
30	29	11-51-010	2014 03 4 12:02:48	1	0:01:23	0:01:23	P	TRANSPORT STC	P202	AA	Procesto	PNLK				MC010F7I	2014 03 4	151	11-51-010	KSL	51	V60

Figure 34 Collected disturbance data for station 11-51-010 from SUSA

7.3.2 Data Processing

The information in SUSA was not presented as desired for simulation input and there was a need of data processing to make format changes and calculations in order to get a usable representation. A MS Excel macro was created, which automatically goes through all MS Excel workbooks in a folder. A new file called InputData_ plus the workbook name was created for all workbooks. This means that it is easy to separate SUSA-data with processed Input-data and that the name contains the station code, e.g. "InputData_S11_51_010". See Figure 35. The created excel shows headlines in Swedish because SUSA is using Swedish. The very first row presents a text of the file used by the macro to retrieve information. Only the first two, or potentially three, columns are intended to be used when adding data into the simulation model. The data presented is in seconds to simplify usage.

Disturbance Start:
YYYY■WW■D■HH:MM:SS

	A	B	C	D	E	F	G	H
1	S11_51_010.xlsx							
2	Förlust	Intervall	Modell		Start störr	Stopp stö	Dag start	Dag stopp
3	82		V60	06:30:00	06:48:53	06:50:15	2	2
4	83	5273	S60	23:59:59	08:18:08	08:19:31	2	2
5	333	2922	S60		09:08:13	09:13:46	2	2
6	850	12246	V70		12:37:52	12:52:02	2	2
7	145	42143	S60		07:04:26	07:06:51	3	3
8	137	2006	S60		07:40:17	07:42:34	3	3
9	165	49225	S60		21:22:59	21:25:44	3	3
10	302	11896	V70		07:14:01	07:19:03	4	4
11	82	128608	V70		08:02:33	08:03:55	1	1
12	384	37446	V70		18:28:01	18:34:25	1	1

Figure 35 Input data sheet in MS Excel for disturbances

Concerning the actual info transformation, “Start störn” (“start disturbance” in English) and “Stopp störn” (“stop disturbance” in English) are timestamps directly taken from the source file “S11_51_010”. This is done to provide transparency to the calculations performed. However, the times have been cleaned from date and spaces to enable MS Excel calculations. By subtracting start disturbance from stop disturbance the “Förlust” (“loss” in English) can be calculated. To make sure the correct “Intervall” (“interval” in English) is calculated “Dag start” (“day start” in English) and “Dag stopp” (“day stop” in English) is used as well as the number of week. Here the very same date-time data has been taken from SUSA as for start and stop disturbance but the middle number for the day is used instead.

7.3.3 Interfacing

No interfacing was done towards SUSA as it was found to be out of the project scope. However, the created macro can be used for any SUSA file which could make a future investigated interface easier.

8 Discussion & Suggestions

In this section several perspectives on the available and required data, presented in the results section, will be further analyzed and discussed to reach a deeper understanding in topic. It will also be discussed how these results can affect the creation of an automated DES model in future. The order will be similar to the result chapter with required simulation model parameters and gap-analysis, followed by more general suggestions connected to the created simulation model.

8.1 Required Simulation Parameters

General required simulation parameters are brought up in the order presented in method and results.

- Processing time
- Disturbances
- Transportation
- Product mix
- Layout
- Steering and process flow

8.1.1 Processing Time

In a utopian factory for a simulation expert, the processing times of the stations would contain representative statistical distributions of a sufficient amount of cycles, which have not been affected by changes in production or any kind of disturbance. The reason behind is that the disturbances should be generated by the simulation model itself and have generate the same result as what happens in reality. Nevertheless on VCT this is not the case because what is registered in the Virtual Device as processing times is affected by disturbances of different kinds.

Processing times of the automatic stations in the Body Shop are normally logged by the PLC´s into the Virtual Device and further calculated by the PLC´s logic at robot and at station level. The user can query, through the OEE portal or directly from the TATS script, the times log of each of the stations. In the process, the robots of a station may have different starting times in their processes in order to avoid colliding with each other; they could also do extra non-value added activities like tip-dressing or tool change before their processing time start. These extra activities depend on factors that are not part of the operations, for example previous and current product variant, number of spot welds since last tip-dress, etc. The frequency of these activities is irregular because they depend on the product mix and the wear of the equipment.

After analyzing the logged information regarding processing times in the different systems, following three main things will be pointed out as inadequate from the team perspective and should be addressed. First, that there is an unclear definition of what is registered as “processing time” in the Virtual Device. The processing times should vary depending on the product variant that is being processed and even within the same kind of product a minor variability is expected, which could be considered as negligible. However it is unclear when a tip-dress check and actual tip-dress is done, and whether tool change or other preparatory action is included in the registries or not. Second, the processing times get disturbed by the alarms within the station. Some robot registers have a very long time since an alarm, read by the PLC, is triggered and this affects somehow the processing time calculation overall. There have been detected cases when the processing time is longer than the cycle time (start-to-start), which is logically impossible. Third, that there is an unclear register of the start and end of the processing time timestamps against transportation times. It was assumed that the processing time would be triggered by the first operating robot and stopped by the last one but it has been observed that is not always the case. Also it is important to note that the “processing times” of the station registered in VD is the complement of the transport system interval within the start-to-start interval.

What has been proposed as trustful times are the Cycle time and start of failure timestamps at the VD. The team considers cycle times as truth since they only involve the income of a new product into a station and alarms can be neglected. Also disturbances start timestamps can be considered as truth because even if alarms overlap each other the first one will have to be cleared before a new product can be processed. Therefore the process of clean cycle times is supported by allocating the start timestamps of the failures from SUSA registers between the cycle times’ timestamps and filtering the ones that do not have any alarm in between. This filtering process will result in cycle times that contain only processing and transport times.

8.1.2 Disturbances

The quality of the disturbance data found in SUSA can be considered insufficient to be used in a simulation model. The disturbance start time is correct but the end time has been observed to be incorrect. When a disturbance occurs the PLC sends out a signal which continues throughout the complete cycle. The full disturbance time detected is thus the actual disturbance time plus the rest of the processing time. This is the case no matter when in the processing cycle the failure occurs. The data can therefore not be considered reliable. Another quality issue is during circumstances when one alarm overshadows another alarm. There can be several failures at once but only on failure alarm will be detected by SUSA. The alarm classification can therefore not be completely trusted for all situations. It does not directly influence the ability to build a simulation model but affects the reading of the simulation results.

There are daily situations where the operator zeroes out the time of failure duration under the headline losses (“förlust” in Swedish). This happens when the station is blocked or starving due to other disturbances in the flow. The operator uses this time to do maintenance or fixing a smaller problem, and it is the opening of the door which triggers an alarm that is recorded in SUSA. The time is thus not adding to the stoppage of the line which means it is not a direct production loss. However, by using this system important statistics get lost which can be necessary in order to predict future maintenance needs and failures, as simulation data input used by the simulation builder.

Availability is another option to using disturbance intervals and duration. Availability can be calculated from the real time data if necessary steps of cleaning the data are taken to achieve enough quality, as discussed previously. By storing the availability in Process Designer it can more easily be accessed, since the intuitive location for employees would be to search for this type of information here. Line-builders can add this information directly in distributed the Line-model and the time consuming task of retrieving the data from them can thus be eliminated. The issue with this solution is that if availability is changed for a specific type of gripper it has to be changed for each single one of these grippers in PD. A way around the updating issue would be to have the availability for each type of gripper, robot, tip weld tool etc. in a separate sheet. When the sheet is updated it should automatically update all resources in the PD with the same name. A standardized naming procedure would therefore be extremely important.

8.1.3 Transportation

For the transportation system with conveyors, elevators, turn-tables etc. there is a lot of information missing. The main problem here is general lack of documented information in a standardized manner. For the investigated lines there was not found documentation on: empty buffer places, indications of body-type-dedicated transport, number of hangers used or speed. Transport times are not registered in any data source but needs to be calculated as an average in how long it takes for one inner-side to travel to the position where it is merged with the matching outer-side.

Line-52, producing right-hand-sides, are having problems with incoming EM-cards on the hanger not being read properly. The wrong body-type can be directed by the roof steering system into a buffer space for a different body-type. When the inner-side enters station 11-52-060 the line stops. This causes problems which are not easily detected and in need of manual support by the Line-maintenance responsible. For instance, a V70/XC70 carrier can be directed to the V60 buffer. Other failures related to the PLC and sensor reading in relation to the ordering system has also been found, but the direct cause has not been detected. The main issue is the future impact these problems would have on an automated model since the quality of data can be viewed deficient. The DES model would not generate trustworthy results.

One aspect which could influence the possibility of creating an automated DES model in the future would be to name the transport systems in the same systematic structure as the lines are named. There are two prime reasons behind this. Firstly, as it is now the lack of name leads to confusion and potential risk of misunderstandings. For instance, between inner sides and outer sides there is EOM transportation, but there is also EOM transportation to inner sides and from outer sides. To have a name on each of these transportation systems would facilitate efficient knowledge exchange. Secondly, a naming procedure would bring importance to the transportation system. In the current VCT body shop factory very little consideration is done to transportation. Focus lies within direct value adding procedures and stations. However there is great potential in addressing transportation issues such as buffers and logic steering. For instance transportation can delimit throughput time if product mix is changed. Overall time efficiency can be improved by directing efforts to handling of the transportation systems.

A DES model can only give assistance here if there is enough available data for the transportation systems, which there is currently not. To summarize, the transportation system information needs to be added somewhere.

8.1.4 Product mix

The product mix is another reason to put focus on the EOM transportation systems on the second floor, between processing lines. The simulation model and investigations of the chosen production scope showed indications on process output changes when changes in the product mix. The reason is the size and product dedication of the buffer places and how locking effects can occur due to this. There are limitations in the system flexibility when it comes to product mix which can reduce or enhance output drastically.

8.1.5 Layout

Updates of the layout have not been done in the AutoCAD™ files for the conveyor systems in the roof, which was used in the thesis. There have also been misunderstandings related to the layout as not all versions had the latest update. However, the thesis did not have access to all the information and had to trust information sources in providing the AutoCAD™ files.

8.1.6 Steering and Process Flow

Steering and process flow became clearer only after several sessions of walking-the-line. The TATS system gives some indication for the floor process but transportation, roof and side lines are more unclear. The Mitsubishi PLC code was investigated but did not provide any clarity because the program is old and badly commented on. This yielded in assumptions from the thesis team in order to simulate the designated production area. However, the PLC signals should be able to send out timestamps for the transportation system as well. Therefore further investigation or redirecting these types of questions to a more knowledgeable person is advised.

8.2 Simulation Model

A good measure of quality of data proposed is to look into two aspects: the availability of data according to its category and the effort of processing it. Regarding availability of data it is important to know how often does the simulation input parameters need to be updated and how much a change could affect the process. The distribution fit is a statistical description of how likely is it for the data to be compared to a statistical distribution. Nevertheless the quality of the data should not be confused to the likelihood of the data with a statistical distribution, the quality of the data should be validated against the sources of it, making sure that the correct data is registered and the amount of further processing effort that need to be done on it in order to make it usable for the simulation modeler.

8.3 Information mapping

The way in which the team proceeded to look for the information required to build the simulation model lead to different challenges to get the information. Some of the information sources resulted to be unusable and unreliable, thus making it difficult to understand the steering of performance of the station resources. When constructing the simulation model the team encountered with the challenge of having an old generation production line that has not been maintained in its virtual documents. Many of the layouts, Process Designer processes and documentation are not updated and contain mayor faults to be considered as complete.

8.4 Suggestions

To enable the StreaMod project the following headlines are suggested to be looked through in order to fill the gaps of lacking information and data. Direct propositions are suggested below together with more general improvements which can be implemented.

8.4.1 Processing times:

- Define what builds up the processing time and what should be considered as preparatory or setup actions (tip-dress, tool change).
- Register the times for each of the robots in a clear way. Take advantage of the different operation trees available at Process Designer to register what the planned time is, use the resource tree to store information about statistical representations of the process if the

attributes defined by default are constant or create customized attributes to include statistical data of the process.

- Standardize format, decimal spaces and decimal separator.
- Increase the availability of historical data in all the stations. Currently a small portion of the available data is visible in OEE portal, 45 days is visible in the TATS script and other in TAP.
- Be aware of VD quality of data within Axxos implementation.

8.4.2 Disturbances:

- The authors propose the use of standardized operator comments in combination of providing the operators with sufficient information to enable an understanding on why the standardization is necessary and should be kept.
- Store availability in Process Designer organized by object. Information is then easier found by more people within the organization as the storage location is intuitive. Updates can be necessary over time as the equipment is used and make it a standardized procedure to have this added by the supplying line-builders.

8.4.3 Transportation:

- Name the overhead monorail transportation systems between lines to avoid confusion, bring importance, and enable a future automatic DES.
- Enable the StreaMod project by adding time stamps when entering and leaving an overhead monorail transportation system.

8.4.4 Layout:

- Update existing AutoCAD files with the added transportation conveyor systems in the roof for the side lines.
- Add indications to buffer places in existing AutoCAD files.

8.4.5 Steering and Process Flow:

- Store logic of lines with stations in an understandable way.

9 Conclusion

The StreaMod project demands data with sufficient quality to enable a future automatic simulation model creation.

9.1 Main changes

What needs to be done in terms of data quality are mainly the following (see *Figure 36*):

- *Steering logic*: Clarification needed in general. Documentation of what logic and conditions drive the interactions between stations, transport systems and alarms management. Also definition on material flow and product type specific processes.
- *Processing time*: From the timestamp of a body entering a station, where the fixtures start operating, to timestamp where the processing is completed. Thus the end timestamp needs to be adjusted to match this and *not* until the next station is *ready* – latter would be a scenario of blocking.
- *Disturbance:* The time for disturbance stop needs to be adjusted to the actual stop, and not the stop of the entire processing.
- *Transportation:* times between lines need to be logged. Perhaps in CTview as a station.

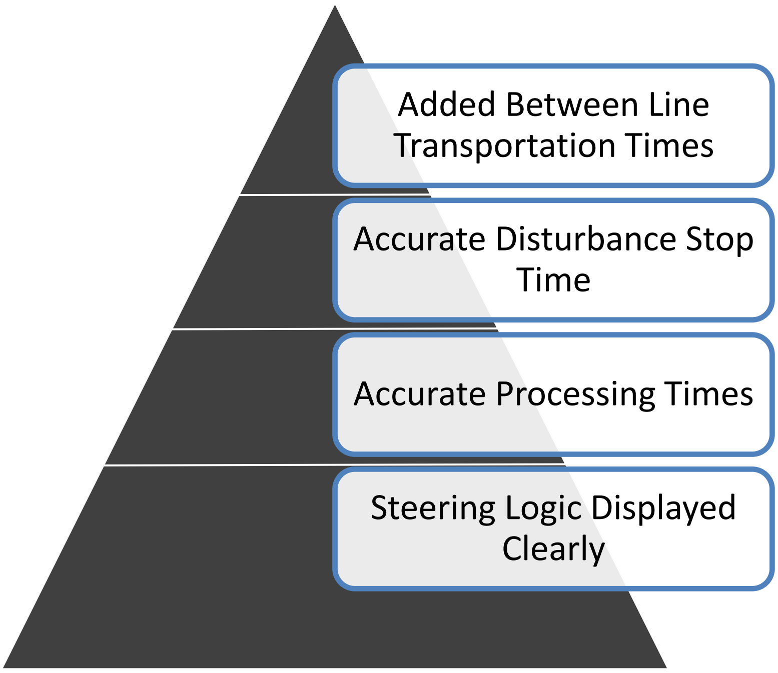


Figure 36 Sand cone model with main priorities displayed bottom-up

9.2 General changes

To enhance the performance and lower manual work time there are additional beneficial parameters to decipher. Furthermore, in the future maintenance and energy utilization are likely two aspects, which will become valuable to investigate with the help of simulation modeling. For mentioned reasons the following data quality concerns need to be looked at:

- Transportation equipment should be updated every second week. Make it a standardized event.

- Buffer capacity should be stored in AutoCAD™ and updated whenever a change in the production process is made, e.g. introduction of new body type.
- Dedication of rails should be stored – perhaps together with steering logic.
- Energy usage can be calculated from processing type and duration.
- Finally, cause identification can be addressed at resource level by adding the different robotic failures to SUSA, thereby achieving better simulation results and maintenance control.

9.3 Suggestions for the future

From the results and based on the conclusion it is suggested that future thesis work should preferably, to benefit the StreaMod project, be in the following areas:

- Data quality in the production with time studies to define errors and create standardization for timestamps and other information.
- Alarm management and disturbance management.
- In combination with above, PLC debugging and creation of new PLC standard.

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Appendix A

OEE for production simulation flow purposes

About OEE Portalen

The OEE Portal is a visualization tool for the TAP database in which the user can extract and visualize information about different operational times at a certain production area. The data can be exported to .CSV, .XLS, or .XML format for further processing. Depending on the station, the data that can be collected from the database include cycle start timestamp in "YYYYWWD HH:MM:SS" format, station processing time, Product variant, and status. Sometimes the station also collects the processing time for each robot separately and transportation time.

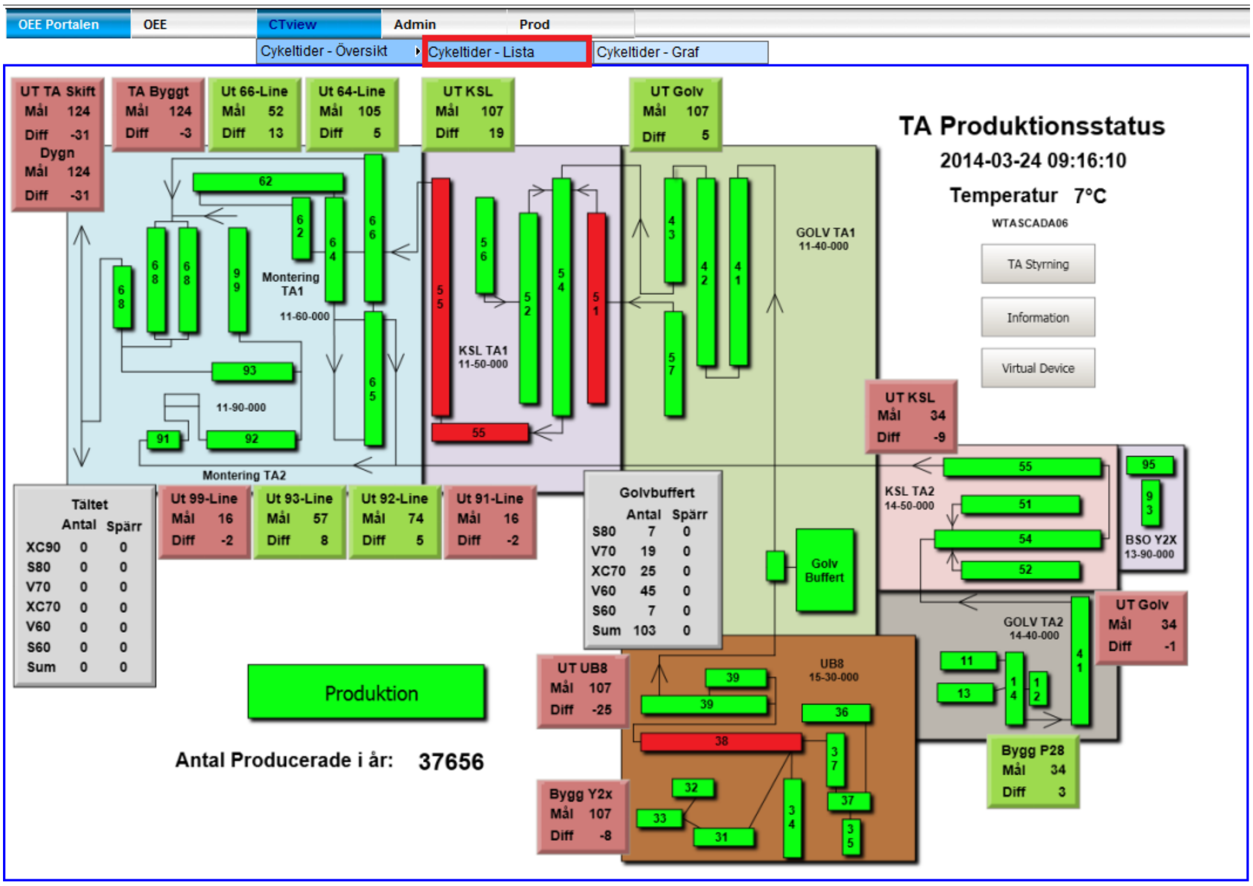


Figure 37 CTview interface in OEE

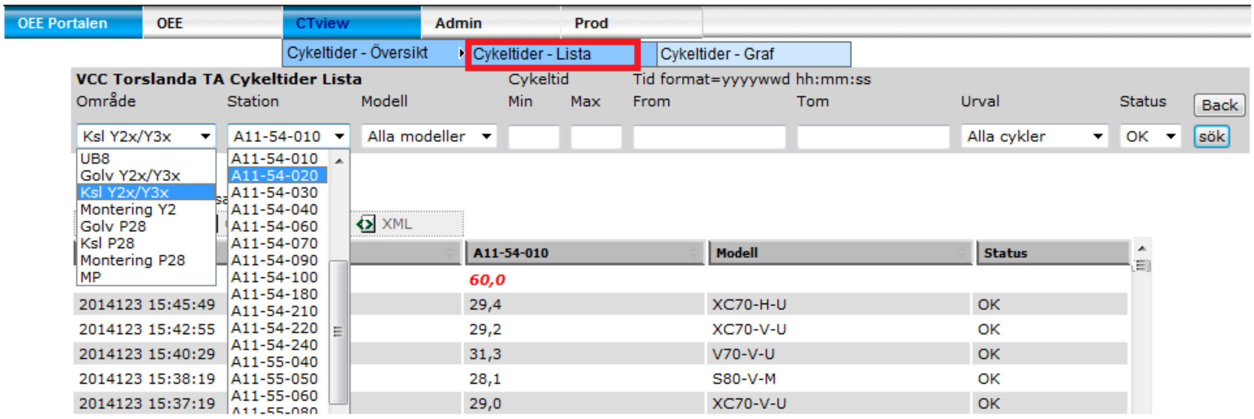


Figure 38 Processing times in CTview

Information useful for simulation

The user can find information regarding processing time for the station, transport time, and cycle time (processing + transport). Depending on the station, different kind of information is collected and displayed. For automatic stations the information is gathered at the Robot level where the user can visualize the processing time for the Robots.

The user can select among the available lines which station will be selected to visualize the historical data. Other filters can be used in combination to make the search narrower. For the automatic stations, there is no need to consider breaks and filter the information out of the registries since the stations are running in automatic mode and do not have any load of material, except for Station 180 which has an operator loading parts in the middle of the station.

Problems with the OEE database

"Cycletidfel" is a failure that is logged in into SUSA and affects Start to start cycle time, but the processing time and the transport remain unaffected. There has been discovered that the transport time is considered only as inbound part flow but not the outbound part flow is considered and therefore there is an unprecise time for the cycle times that needs to be addressed. As shown in the figure below, a concept of "clean cycle times" has been used to identify the cycle times registered within the shift and without any disturbance. In that way only the processing and transport time will be shown in the registries start-to-start and compared to the registered transport times. After such comparison it has been discovered that a missing average of 4.9 seconds corresponds to the inexistent outbound transport of the parts from the station. With this assumption, the average cycle time would be increased to 12.93 seconds.

Appendix B

Using SUSA for production flow simulation purposes

About SUSA

SUSA is an internally developed application that logs all the downtimes information of the production lines at the TA shop. This system is used by simulation and maintenance engineers to track and follow up disturbances at the different stations. It collects and filters the data from the "Virtual Device" database, which receives the PLC´s raw data from the production floor.

Warnings about SUSA

The empirical studies made by the team at one of the stations (11-54-020) suggest that the log of failures into SUSA is not as reliable as expected regarding duration and mode of failure. In the case that a failure occurs in a resource of a station, a first alarm will be triggered and its timestamp will be registered in SUSA. The duration of the failure is observed to be from the start of the failure until the end of that complete cycle, including outbound transportation of the product. In case that a second resource fails SUSA will only register the first cause of alarm and ignore all consequent alarms until the end of the current cycle.

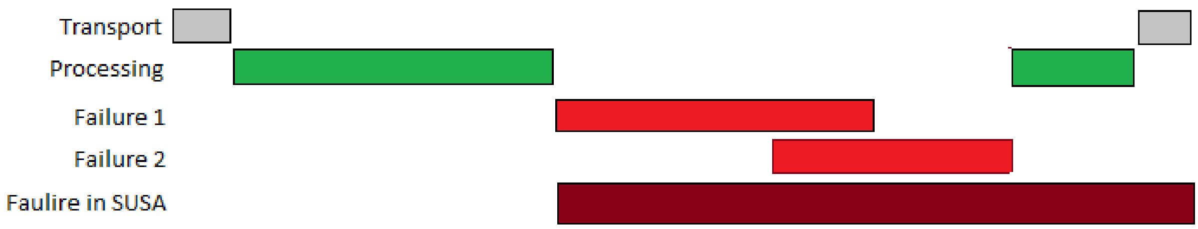


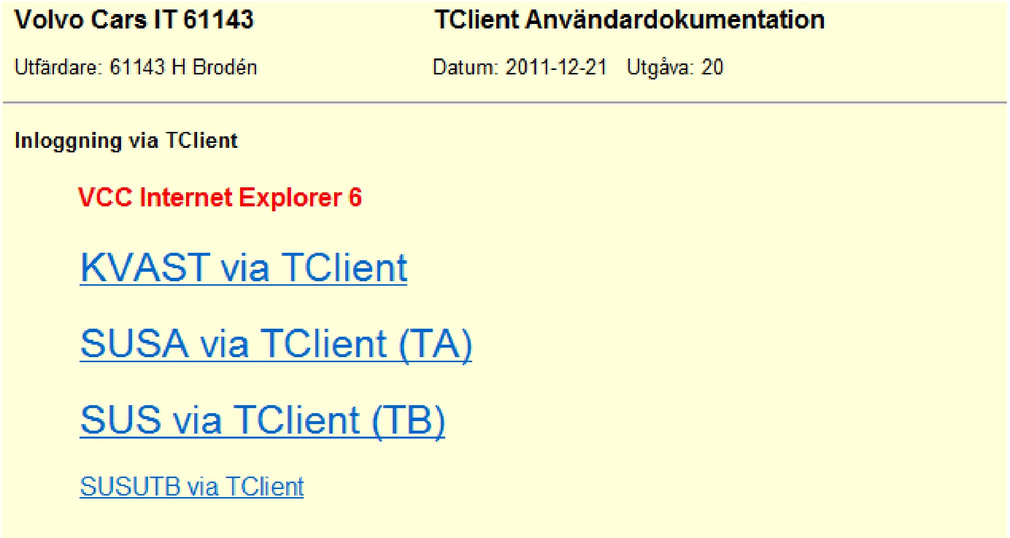
Figure 39 Logged signals in SUSA

It is also important to note that the operator has the possibility to declare when a disturbance register relates to a production loss or not. In case the disturbance does not affect the production then the operator would normally delete the time out of the "förlust" (loss) field. The operator can comment out the disturbances too but there is not a clear definition of when a comment

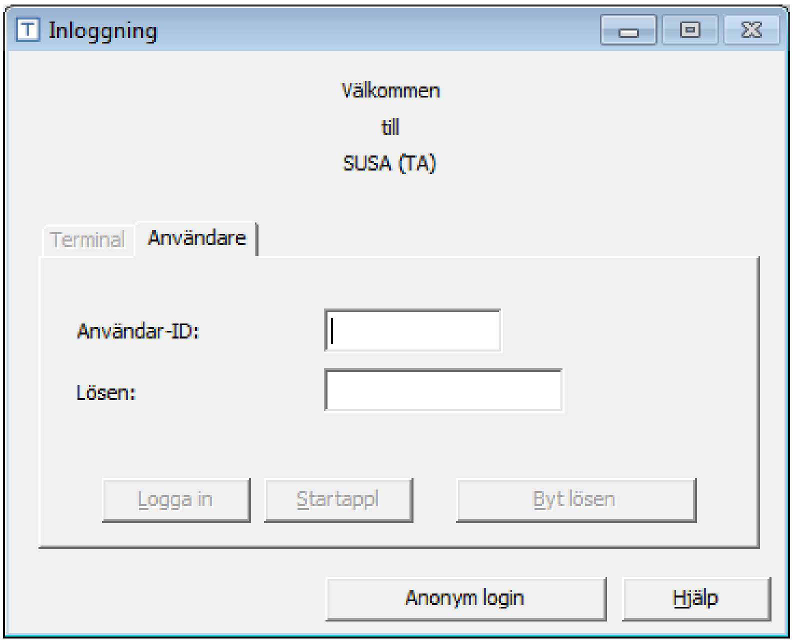
To open SUSA go into the following link:

http://wwwapp.gothenburg.vcc.ford.com/prodrapp/tclient/javaplugin.htm

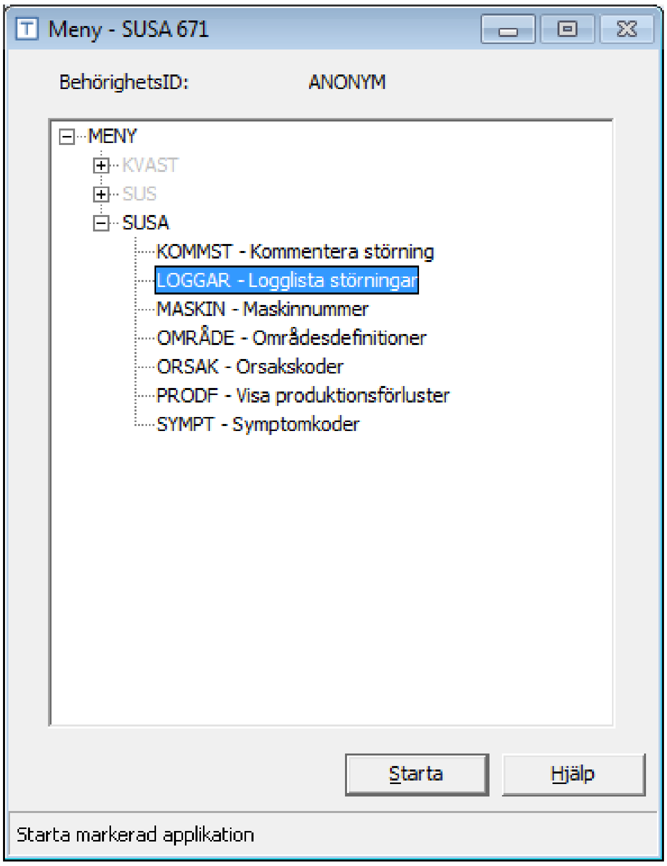
To work with VCT body shop click on "SUSA via TClient TA"



To enter into the system log in anonymously ("Anonym login"):



Start the LOGGAR application.

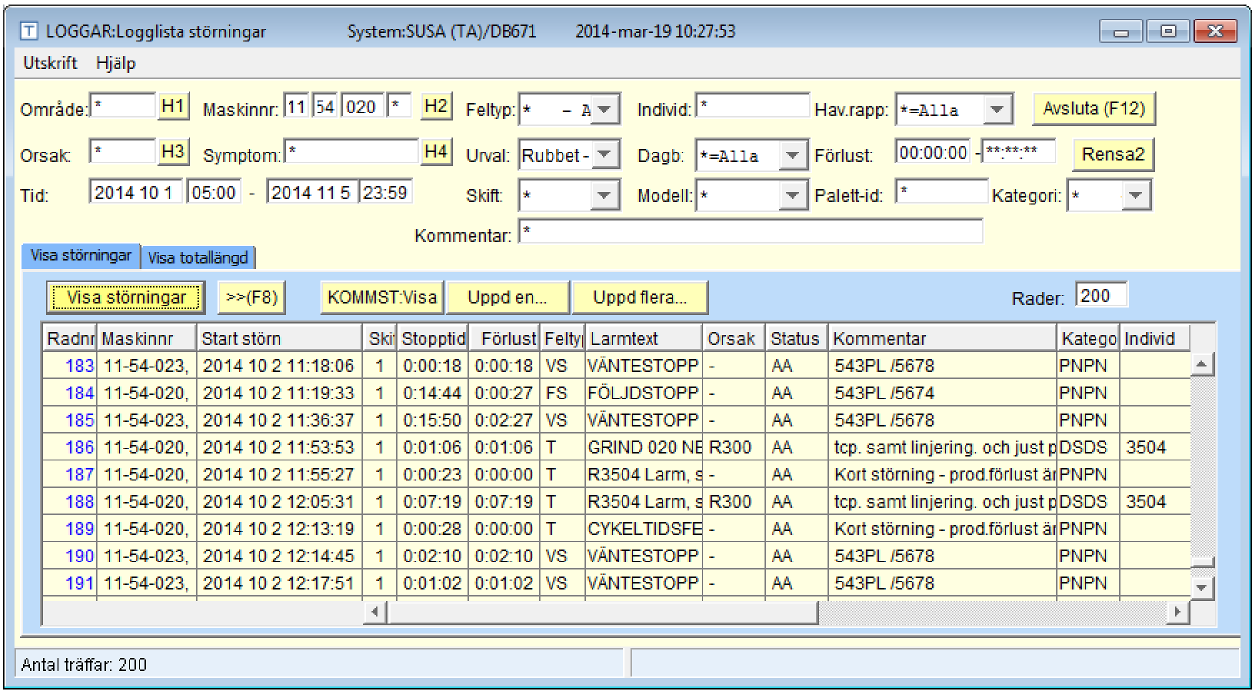


In this application the user can search and filter all the down time registers for a specific line or station. The registers can be then visualized in a table that contains the machine number, start and stop timestamp of the down time, shift, down time duration (stopptid), down time duration that can be considered as production loss (förlust) , system´s failure description, cause, comment editable by the operator, and others not as relevant for this thesis purpose.

It is important to mention that the timestamps of start and stop of failures are in the following format:

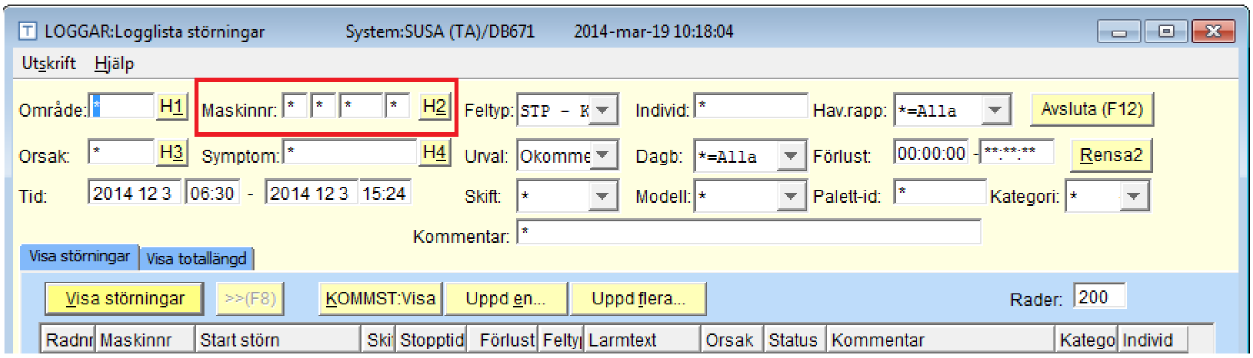
“YYYY WW D HH:MM:SS”, where YYYY is the year, WW the week of the year, D is the day of the week (e.g. 1= Monday, 6=Saturday), and HH:MM:SS the actual timestamp in that day.

After the results are displayed in the screen they can be copied and pasted on a conventional spreadsheet for further data processing or documentation purposes.



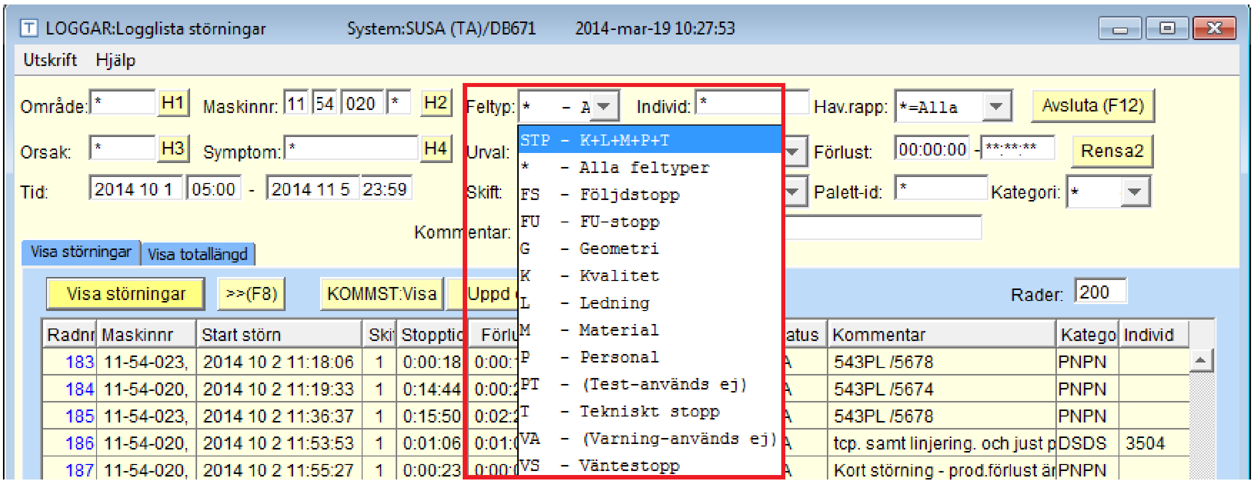
To narrow you search the user can use the following available options:

Maskinnr – Number of machine or station. In this field the number of the station can be added. The first 2 digits represent the site or facilities in Volvo Cars (For example, 11=Torslanda A-shop 1 or TA1, 13=BSO Y2X, 14= TA2, 15=UB8). The second 2 digits field represent the line number (For example, 54= Framing, 55= Respot). The next 3 digits are the number of the station (for example 020 = Framing station, 010 = Ringframe).

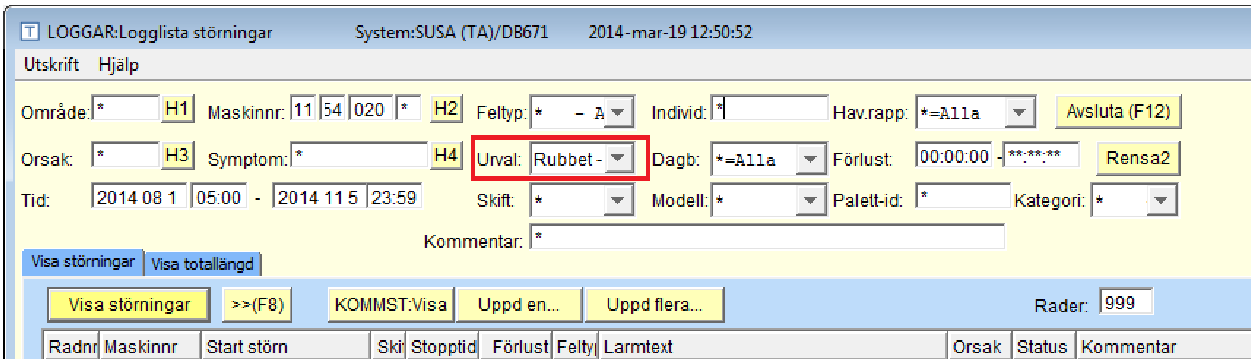


Felltyp – Type of failure. Describes the mode or reason of failure. K= Quality related, L= Related to the station, M=Material (not used), P=Related to Personnel mostly when breaking through a safety area. T= Technical Failure caused by the equipment or process in the station (most common and relevant).

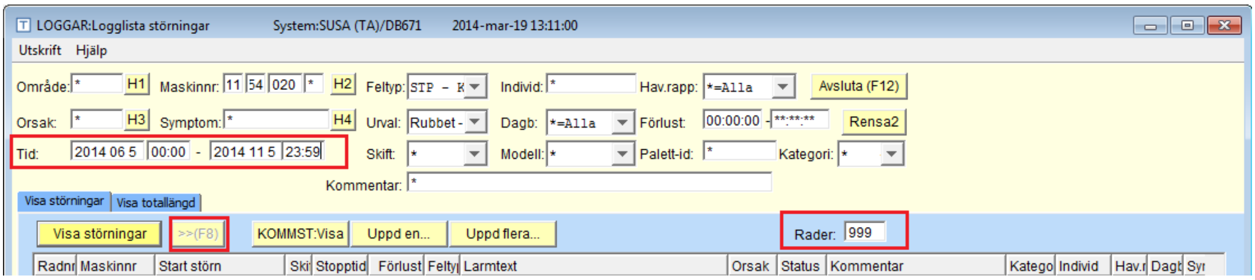
Waiting (VS- väntestopp) and blocked (FS- följdstopp) times are also registered in SUSA as down times even if they are consequence of the upstream and downstream production system. A good filter to visualize only station related down times is STP (K+L+M+P+T).



A common way to see all the available information in SUSA is by setting the attribute "Urval" (selection) to "Rubbet" (whole lot) must be selected:



The system has a restriction regarding historical data. The user can display maximum 999 registries (Rader) in the screen at once, for a maximum time lapse period of 35 days. The user can advance to the next page of registries by pressing F8 key. These 35 days interval can be adjusted to prior dates following the specified previous format "YYY MM D" & "HH:MM". The earliest available data is around week 37 of 2011.



Appendix C

TATS - (TA Terminal Services)

TATS Script is an information source used by the thesis team to collect the data regarding processing and cycle time for each of the stations involved in the study case. It has been used because it is the information source that provides the largest amount of historical information of timestamps that are collected by the Virtual Device. TATS Script runs over a website developed internally by VCT in which information about the Virtual Device and production equipment can be displayed. It is one of the most used resources for manufacturing engineers at VCT to monitor the activity of the current production and contains relevant links to other frequently visited internal websites.

In order to run the TATS Script, the user has to clic on “CT View to Excel” under the “Buffert” menu, this action will result in the generation of an excel file that contains the information of a default station. In order to use this Script and access the information of other stations, the user has to manually change the URL address in the internet browser and write the number ID of that specific station. Figure XX shows the URL address segments that the user has to adjust to generate the desired excel file. Then the user can download the generated excel file from the link displayed on the website.

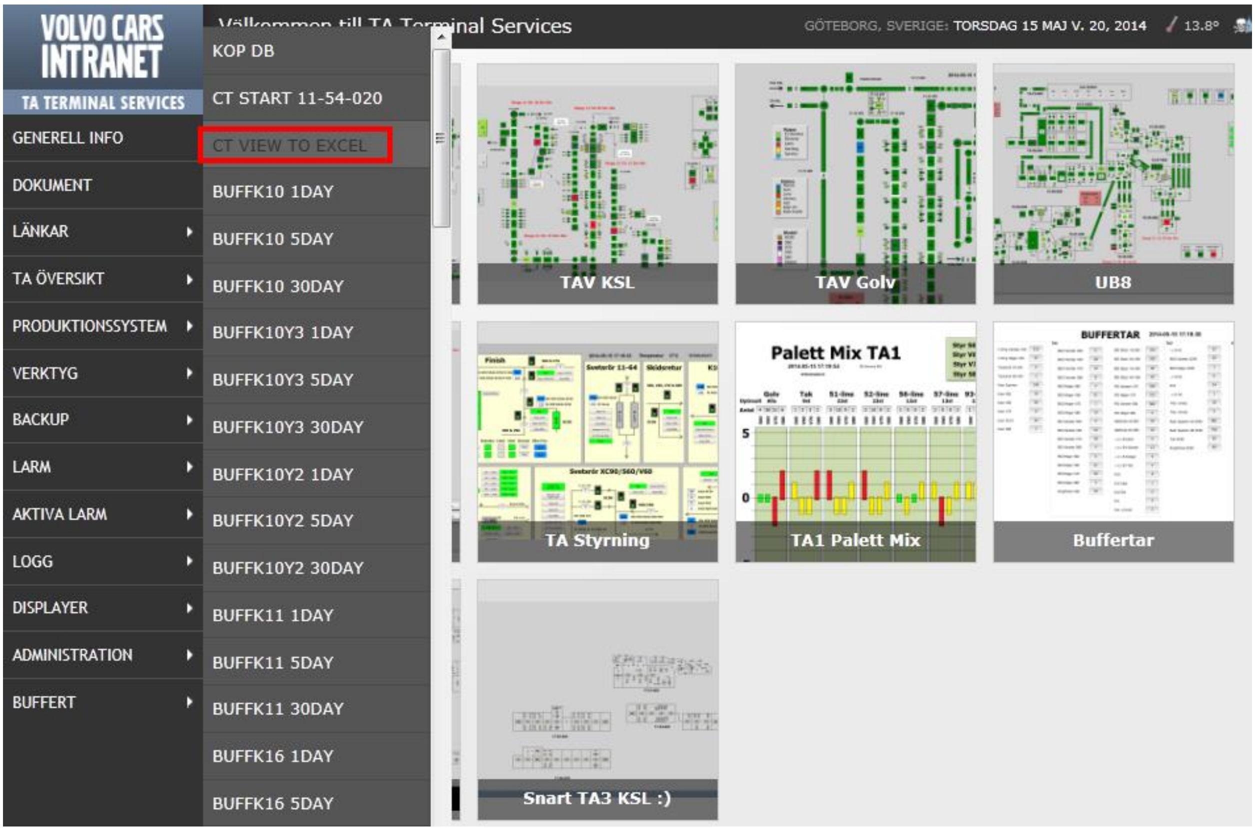


Figure 40. Access to TATS Script tool.

Figure 41. Edited Station identifier and generated file link.

After the user downloads and opens the file it can be appreciated that the processing time for the station is displayed under the header "CT" with a comma decimal separator and the timestamp is displayed with a regular calendar date and time format. Also the product variant and delta is generated.

The disadvantage of using TATS Script over CTview is that CTView provides the user the transport time and for teach of the robots the processing times and special actions.

On the counter side, the advantage is that the timestamp in TATS Script is already in a calendar regular date and time format and that the Delta times are automatically calculated. Also, that the historical availability of the registers is larger in the TATS generated file than the one in CTView.

	A	B	C	D	E	F
1	ART Query: CTTS - 2014/05/15-17:42:51					
2	machinenr	time_stamp	CT	kk	delta	status
3	A11-54-020	2014-04-02 22:48:03	53,2	V70-V-U-Ra	66	OK
4	A11-54-020	2014-04-02 22:49:09	55,4	V60-V-M	70	OK
5	A11-54-020	2014-04-02 22:50:19	53,2	V70-V-U-Ra	64	OK
6	A11-54-020	2014-04-02 22:51:23	51,5	V60-V-M-Ra	58	OK
7	A11-54-020	2014-04-02 22:52:21	46,3	S60-V-M-B1	22	OK
8	A11-54-020	2014-04-02 22:52:43	46,3	OkÃ¤nd (0)	61	OK

Figure 42 TATS Script

Appendix D

Results of the Simulation Model

The simulation model was run for a period of 20 days. The expectation of the data collection and processing was to have only clean cycle times that contain only processing and transport times, excluding the disturbances in the system. This expectation was not accomplished since the resultant filtered times, as explained in section **Error! Reference source not found.**, still contained samples asting much longer than the designed cycle time at planning stages. This result arised several questions regarding the alarm management at the PLC´s and the reliability of the logged disturbance timestamps.

In the first experiment, for practical purposes the thesis team decided to feed the simulation model with the processed cycle times as triangular distributions and failures as empirical functions for the lines 51, 52 and 54. The result was significantly lower than the actual production at VCT, invalidating the simulation model results. Figure XX shoes that the throughput for this experiment is around 25 jobs per hour (JPH) and around 600 throughput per day.

Object	Working	Set-up	Waiting	Stopped	Failed	Paused	Mean Life Time	Mean Exit Time	Total Throughput	Throughput per Hour	Throughput per Day
L11_55	93.24%	0.00%	4.18%	0.00%	2.57%	0.00%	4:21:58.9740	2:22.0085	11559	25.348684	608.36842

Figure 43. Output statistics

A second experiment was designed based on two assumptions. First, that the failures registers are unreliable and that disturbances are embedded in the processed cycle times. Second, that the processed cycle times can fit into Triangular and Normal Distributions since they are automated processes. The experiment was designed with two levels. The first level of the experiment was using as Processing times the collected information with a triangular distribution function and the second level was using a normal distribution function. The days were considered as full 24 hour working periods and no failures have been setup in any of the stations. Figure 44 shows that the simulation outputs in average 46.44 jobs per hour for a normal distribution and 43.19 jobs per hour for a triangular distribution with a confidence level of 90%.

	Normal or triangular	Throughput per Day	JPH
Exp 1	Normal Distribution	1114.78947368421	46.4495614035088
Exp 2	Triangular Distribution	1036.75263157895	43.1980263157895

Figure 44. Second experiment simulation results

These previous results are more likely to be a valid representation of the system since a regular 2 shift working day (06:30 to 00:00 hrs) has a throughput of around 720 car bodies.

Some other interesting outputs from the simulation model for manufacturing engineers were uneven utilization of resources. Left and right BSI lines had different amount of fixture changes to cope with the product mix. Also the amount of dedicated fixtures for each product type was not optimal. Figure 45 and Figure 46 show that one S60 fixture could be taken away from the system but is not the same case for the other product types.

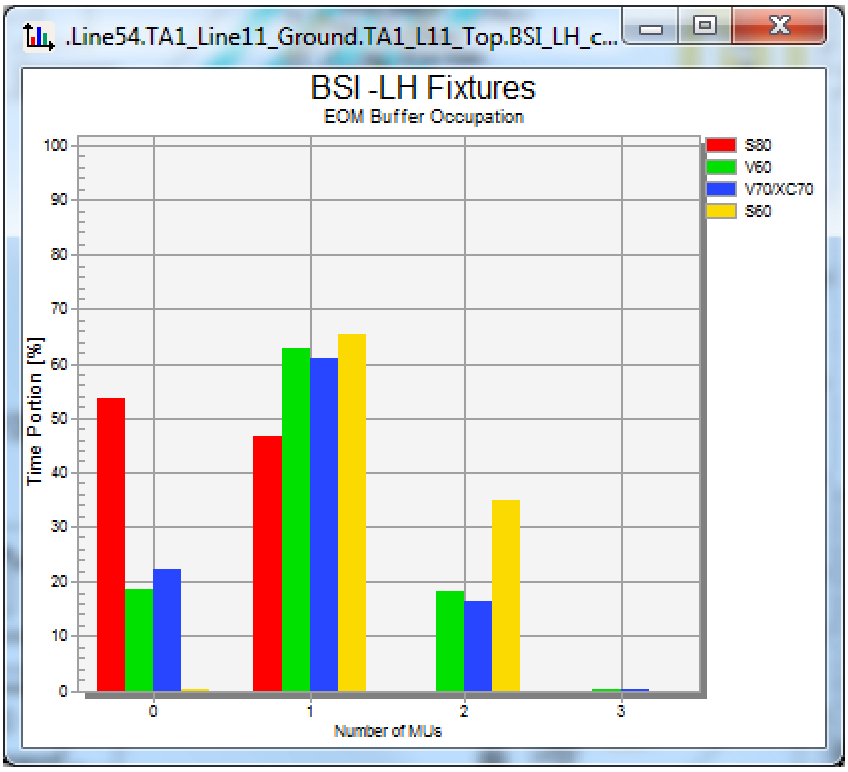


Figure 45. BSI -LH buffer utilization.

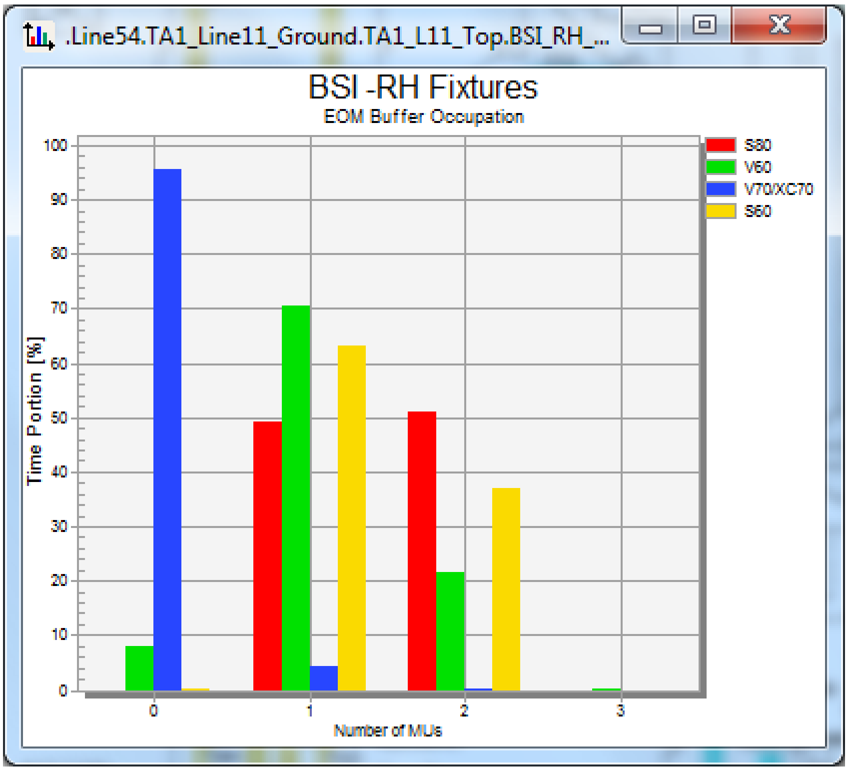


Figure 46. BSI -RH buffer utilization.